

Characterization of University Parking System

Center for Transportation, Environment, and Community Health
Final Report

by

Ruey L. Cheu, Okan Gurbuz, Esmaeil Balal, H.
Michael Zhang, H. Oliver Gao, Yu Zhang

October 2018

Disclaimer

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the information presented herein. This document is disseminated in the interest of information exchange. The report is funded, partially or entirely, by a grant from the U.S. Department of Transportation's University Transportation Centers Program. However, the U.S. Government assumes no liability for the contents or use thereof.

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Characterization of University Parking System		5. Report Date September 30, 2018
		6. Performing Organization Code
7. Author (s) Ruey L. Cheu, Okan Gurbuz, Esmaeil Balal, H. Michael Zhang, H. Oliver Gao, Yu Zhang		8. Performing Organization Report No.
9. Performing Organization Name and Address Department of Civil Engineering The University of Texas at El Paso 500 West University Ave. El Paso, Texas 79968		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. 69A3551747119
12. Sponsoring Agency Name and Address U.S. Department of Transportation		13. Type of Report and Period Covered 1/16/2018 to 8/30/2018
		14. Sponsoring Agency Code
Supplementary Notes		
16. Abstract <p>Most universities are constantly challenged by the parking congestion problem. As one of the initial steps towards finding the solutions, this research set out to: (1) understand the parking demand and management strategies at four different university campuses; (2) identify innovative solutions to manage parking demand and supply on university campuses; and (3) propose a framework to analyze the relationship between parking management on a university campus with the environment and community health. To meet the first objective, the parking demand and supply managements at four selected universities, namely Cornell University (Cornell), The University of Texas at El Paso (UTEP), University of California at Davis (UCD) and University of South Florida (USF) were reviewed, analyzed and compared. For the second objective, this report surveyed the parking management practices in more than 300 universities and summarized innovative implementations of zoning, permit sales, pricing, access control, visitor payment, data collection, guidance, enforcement and multimodal integration. For the third objective, a framework based on the VISSIM microscopic traffic simulation followed by emission estimation using the CMEM emission estimation model has been proposed. A case study was performed, using UTEP campus as an example, to illustrate the application of the proposed framework. The VISSIM-CMEM framework estimated that the vehicle headed to UTEP parking lots between from 8:00 a.m. to 9:00 a.m. contributed 248,707 kg of CO₂.</p>		
17. Key Words Parking, university campus, intelligent transportation system, emission.		18. Distribution Statement Public Access

ABSTRACT

Most universities are constantly challenged by the parking congestion problem. As one of the initial steps towards finding the solutions, this research set out to: (1) understand the parking demand and management strategies at four different university campuses; (2) identify innovative solutions to manage parking demand and supply on university campuses; and (3) propose a framework to analyze the relationship between parking management on a university campus with the environment and community health. To meet the first objective, the parking demand and supply management at four selected universities, namely Cornell University (Cornell), The University of Texas at El Paso (UTEP), University of California at Davis (UCD) and University of South Florida (USF) were reviewed, analyzed and compared. For the second objective, this report surveyed the parking management practices in more than 300 universities and summarized innovative implementations of zoning, permit sales, pricing, access control, visitor payment, data collection, guidance, enforcement, and multimodal integration. For the third objective, a framework based on the VISSIM microscopic traffic simulation followed by emission estimation using the CMEM emission estimation model has been proposed. A case study was performed, using UTEP campus as an example, to illustrate the application of the proposed framework. The VISSIM-CMEM framework estimated that the vehicle headed to UTEP parking lots between from 8:00 a.m. to 9:00 a.m. contributed 248,707 kg of CO₂.

ACKNOWLEDGEMENTS

This Research is funded by The Center for Transportation, Environment and Community Health (CTECH) awarded by the U.S. Department of Transportation under Contract 69A3551747119. The authors would like to thank the following subject experts for sharing their professional knowledge:

- Reed Huegerich, Senior Planner at Cornell University; and
- Dr. Tingting (Tina) Zhao, Postdoctoral Researcher at University of South Florida.

In addition, the research team thanks the following assistants for their efforts in the data collection process:

- Fernie Briones and Emiliano Ruiz, Undergraduate Student Assistants at The University of Texas at El Paso.

TABLE OF CONTENTS

Abstract	iii
Acknowledgements	iv
Table Of Contents	v
List Of Figures	viii
List Of Tables	ix
1. Introduction	1
1.1. Motivation	1
1.2. Objective	1
1.3. Significance	1
1.4. Outline of Report	2
2. Research Work Plan	3
3. Review for Parking on University Campuses	4
3.1. Parking Demand	4
3.2. Parking Supply	5
3.3. Demand-Supply Interaction	6
3.4. Search Time	6
3.5. Zoning	6
3.6. Permit Price	7
3.7. Permit Cost	7
3.8. Class Schedule	7
3.9. Availability of Transit	8
4. Parking Demand and Supply Management on University Campuses	10
4.1. Cornell University	10
4.1.1. General Information	10
4.1.2. Parking Information	11
4.1.3. Sustainability	13
4.1.4. ITS in Parking and Transportation	14
4.2. The University of Texas at El Paso	14
4.2.1. General Information	14
4.2.2. Parking Information	15
4.2.3. Sustainability	17
4.2.4. ITS in Parking and Transportation	17
4.3. University of California at Davis	19
4.3.1. General Information	19
4.3.2. Parking Information	19

4.3.3.	Sustainability	23
4.3.4.	ITS in Parking and Transportation	23
4.4.	University of South Florida	24
4.4.1.	General Information	24
4.4.2.	Parking Information	24
4.4.3.	Sustainability	26
4.4.4.	ITS in Parking and Transportation	27
4.5.	Comparison of the Universities	28
5.	Innovative Solutions	30
5.1.	Chapter Introduction	30
5.2.	Zoning.....	31
5.2.1.	Free remote parking	31
5.2.2.	Overflow lots	31
5.2.3.	Zones based on seniority	32
5.2.4.	Underutilized parking.....	32
5.2.5.	Zoning in parking garage	32
5.2.6.	Zone identification	33
5.3.	Permit Sales and Pricing.....	33
5.3.1.	Occasional parking permits	33
5.3.2.	Prioritization in permit sales	33
5.3.3.	Restrictions.....	34
5.3.4.	No physical permit	34
5.3.5.	Day based permits	34
5.3.6.	Pricing strategies	35
5.4.	Access Control.....	35
5.5.	Visitor Payment	35
5.5.1.	Smart device payment through apps	35
5.5.2.	Online visitor permits.....	36
5.6.	Data Collection and Guidance.....	36
5.6.1.	Manual survey informing users	36
5.6.2.	Real-time occupancy information	37
5.7.	Enforcement.....	38
5.8.	Multi-modal Integration	38
6.	Parking, Environment and Community Health.....	40
6.1.	Metric of Community Health	40
6.2.	Modeling Framework	40

6.2.1. Simulation Tool.....	41
6.2.2. Comprehensive Modal Emissions Model	41
6.3. Modeling Procedure	42
6.4. Demonstration	45
7. Conclusions.....	49
8. References.....	51

LIST OF FIGURES

Figure 1 - Student parking lots at Cornell University	12
Figure 2 – Faculty and staff parking lots at Cornell University	13
Figure 3 – Parkmobile smartphone application	14
Figure 4 - Parking zones at The University of Texas at El Paso	16
Figure 5 - DoubleMap Bus Tracker smartphone application.....	18
Figure 6 - “C” and “L” parking zones at University of California at Davis	21
Figure 7 - “A” parking zones at University of California at Davis	22
Figure 8 - EasyPark mobile device	23
Figure 9 - Parking zones at University of South Florida	25
Figure 10 - MyUSF smartphone application	27
Figure 11 - Popular smartphone applications used for campus parking	36
Figure 12 - Texas A&M University parking stall occupancy system.....	37
Figure 13 - Auburn University real-time stall information smartphone application	38
Figure 14 - VISSIM evaluation tab.....	43
Figure 15 - VISSIM vehicle record - configuration.....	43
Figure 16 - CMEM activity tab.....	44
Figure 17 - CMEM CO ₂ output	45
Figure 18 - Street map of The University of Texas at El Paso campus	46
Figure 19 - Screenshot of VISSIM with the completed network.....	47
Figure 20 - Parking zones at The University of Texas at El Paso	48

LIST OF TABLES

Table 1 - Cornell University population (Fall 2017)	10
Table 2 - Student parking permits at Cornell University	12
Table 3 - The University of Texas at El Paso population (Fall 2017)	15
Table 4 - University of California at Davis population (Fall 2017)	19
Table 5 - University of South Florida population (Fall 2017)	24
Table 6 - Student parking permits at University of South Florida.....	26
Table 7 - Comparison of demographics and infrastructure conditions.....	28
Table 8 - Comparison of sustainability practices and ITS applications.....	29
Table 9 - Parking garage zoning at The University of Texas at Dallas	33

1. INTRODUCTION

1.1. Motivation

Parking congestion problem occurs when the demand for parking stalls exceeds the capacity of the parking lots. On university campuses, the number of stalls allocated for parking in the master plan may be sufficient to meet that the parking demand of faculty, staff, students and visitors in the initial years. However, as the student enrollment continues to grow, the limited land space on campus is usually used to build new classrooms, offices and laboratories, i.e., the infrastructures that are deemed more important to serve the mission of the university, rather than parking facilities. Thus, many university parking offices turn to management strategies and Intelligent Transportation Systems (ITS) to cope with parking congestion problem, rather than capacity expansion.

Parking is an attribute in the trip destination and mode choice decision making process. Therefore, it can be stated that access to parking is a factor that determines if and how users come to a university campus. On the other hand, because most of the campus users have their own fixed class or work schedule, the parking demand is relatively inelastic. However, the demand can still be managed by a combination of parking price and by providing alternative modes of transportation, i.e., shifting users' mode choices from driving private vehicles to taking public transportation, carpool, etc. Another approach to solve the campus parking congestion problem is to tackle the supply side; that is, implementing policies for better control of parking stall usage, and use ITS to make the stall usage more efficient.

The difficulty of finding a parking spot not only contributes to traffic congestion within a parking lot (and garage) but also the surrounding streets. While seeking an empty stall to park, the idling and circulating vehicles also increase emission and negatively affect community health. One way to increase the public and university decision makers' awareness on the importance of parking is to increase the understanding of the impacts of parking on the environment and community health, so that parking projects (whether construction of new parking stalls or congestion mitigation) can receive a higher priority in the campus planning process. This report analyzes parking demand and supply problems on university campuses and identifies innovative solutions.

1.2. Objective

The objectives of this research are: (1) to understand the parking demand and management strategies at four different university campuses; (2) to identify innovative solutions to manage parking demand and supply on university campuses; and (3) to propose a framework to analyze the relationship between parking management on a university campus with the environment and community health.

1.3. Significance

This project examines the parking demand and supply management strategies at large university campuses. It is also very likely to be the first that links parking on university campuses to environmental impacts and community health. The literature reviewed in this research and the

tools developed are applicable to most university campuses. These are tools for the University Parking Offices (UPOs) to analyze the parking demand and supply, and the nature, location and time of parking congestion. The methodologies also estimate the environmental footprint (air quality impact) caused by parking. The baseline indicators and the simulation model allow transportation planners, engineers and analysts to evaluate the impacts of any policy change with regards to parking management on campus.

1.4. Outline of Report

This report is outlined as follows. After this Introduction, Chapter 2 describes the research work plan. Chapter 3 reviews background materials. Chapter 4 presents the parking conditions at four selected universities. Chapter 5 shares the innovative solutions found in other universities and Chapter 6 proposes a framework to analyze the links between parking management, environment, and community health. This chapter also includes a case study to demonstrate how the proposed framework can be applied to estimate the impact of implementing an innovative parking solution.

2. RESEARCH WORK PLAN

This chapter describes the work plan performed to meet the objective of this project. The work plan for this research consisted of the following tasks:

Task 1: Review of university campus parking

At the beginning of this project, important works concerning the topic of university parking were reviewed. The reviews were summarized in Chapter 3 of this report.

Task 2: Data collection and operation analysis

In this task, parking inventory and usage data were collected from four universities: Cornell University (Cornell), The University of Texas at El Paso (UTEP), University of California at Davis (UCD) and University of South Florida (USF). The parking demand, supply, and management strategies were analyzed in detail and compared. The findings were compiled into Chapter 4 of this report.

Task 3: Proposed innovation solutions

This task started with identifying the university campuses in the United States, which have more than 10,000 students. Aggregated parking data and student demographics at these universities were collected from publicly available sources. The data collection included parking management practices and innovative solutions. The innovative solutions were organized and presented in Chapter 5 of this report. Finally, several innovative solutions were suggested to improve parking management at Cornell, UTEP, UCD, and USF.

Task 4: Parking, environment and community health

In this task, which is Chapter 6 of this report, a framework to analyze the relationship between parking management, its impact on environment and community health was proposed. A case study was performed, using UTEP campus as an example, to illustrate the application of the proposed framework.

3. REVIEW FOR PARKING ON UNIVERSITY CAMPUSES

Parking facilities are important infrastructure components of the highway transportation systems. Every vehicle trip is associated with parking at the trip origin and the destination. According to the survey conducted by the American Automobile Association ([AAA 2017](#)), the average time a vehicle spent traveling on roadways was 48.2 minutes/day. For the rest of the day, this vehicle was parked at a stall.

This chapter reviews literature and materials that were published in public sources concerning parking on four university campus. The relevant information is organized according to the following sequence. First, we discuss what are parking demand and parking supply on university campuses. These are followed the outcome of demand-supply interactions, and the performance indicators. Special attention is paid to parking search time. The review continues with factors that affect the supply of parking facilities for commuting students: zoning and permit price. We then review the factors that determine the parking demand generated by students: permit cost, class schedule, availability of transit, and etc.

3.1. Parking Demand

A university campus houses different types of facilities such as classrooms, laboratories, offices, libraries, dormitory, dining halls, auditoriums, sports venues, and etc., like a small city ([Shoup 2017](#)). These infrastructures attract different users such as students, faculty members, staff, and visitors, each with its unique trip characteristics (frequency, arrival and departure times) which generate different parking demands. In general, parking demand is affected by geographic, demographic and economic factors ([Litman 2018](#)). Some of the factors will be discussed later in this chapter.

University campuses are traffic analysis zones with unique trip generation and trip attraction rates. The estimation of parking demand is a very complex subject because the demand is affected by many variables than simple statistics suggest. The Institute of Transportation Engineers (ITE) Parking Generation Handbook ([ITE 2005](#)) relates parking demand to some measurable factors such as the size of the study site, occupancy of the site, density and charges for parking. The database used to develop the parking demand models consisted of a mix of suburban and urban campuses. The average parking demand rates at the suburban and the urban sites were analyzed separately:

- At suburban campuses: 0.33 stalls per students, faculty, and staff;
- At urban campuses: 0.22 stalls per students, faculty, and staff.

Gurbuz et al. ([2018](#)) developed a parking demand model using aggregated data from 172 university campuses that had enrollments of at least 10,000. The model takes the form of

$$\hat{Y}_1 = \frac{\exp(\mathbf{x}\hat{\beta})}{1 + \exp(\mathbf{x}\hat{\beta})} \quad (1)$$

where \hat{Y}_1 is the estimated or predicted value of Y_1 , the fraction of the student population who will purchase parking permits; while \mathbf{X} is the row vector of input values and $\hat{\beta}$ is the column vector of the coefficients:

$$\mathbf{x}\hat{\beta} = 0.019X_6 - 0.00000915X_8 - 1.349X_{10} + 3.134X_{11} - 0.002X_{18} \quad (2)$$

The independent variables are:

- X_6 = average fall semester temperature;
- X_8 = tuition fee (in state, fall and spring semesters);
- X_{10} = proportion of undergraduate students;
- X_{11} = proportion of part-time students; and
- X_{18} = base permit price per year.

3.2. Parking Supply

The supply and management of a university's parking facilities is the responsibility of the UPO. In parking management, the supply of parking stalls not only refers to the provision of physical space of the stalls, but also includes the policies that control who can use the stalls at what time and at what price. Construction of new parking facilities is a long-term solution to increase the parking supply. In the short-term, zoning and permit price are the most common supply management tools used by UPOs to moderate the parking demand.

Effective parking management can reduce parking demand by 20% to 40% yet provide economic, social and environmental benefits (Litman 2018). One important element in parking management is defining the long-term supply of parking stalls in the university campus master plan. Isler et al (2005) surveyed 34 universities and found that master plans generally place open parking lots in remote locations, in plots of land that could be used to build new buildings in the future.

Increasing parking supply by constructing new parking facilities is an easy solution, if space and budget are both available. The construction costs are: (i) \$1,000 to \$3,000 per stall in an open surface parking lot; (ii) \$8,000 to \$15,000 per stall in a multi-story parking structure; and (iii) \$20,000 to \$30,000 per stall in an underground parking garage (ITE Technical Council Committee 2005). These values are in 2005 dollars. The current costs after adjusting for inflation are expected to be higher. The income from the sales of parking permits is insufficient to cover the construction cost of parking stalls. The Institute of Transportation Engineers (ITE) Traffic Engineering Handbook (ITE 2016) summarized the typical annual cost to operate a new parking facility. For an open parking lot, the annual operating cost was between \$600 to \$1,320 per stall. For a multistory parking structure, the annual operating cost was between \$2,040 to \$3,360 per stall. In another study, Kenney (2004) calculated that, for every 1,000 parking spaces, a university loses \$400,000 per year for a surface parking lot and more than \$1.2 million for a parking garage. In public universities, UPOs are self-funding units which means that income from tuition and state budget cannot be used for the university parking expenses. The universities often have to pay for the construction cost as much as possible using building development fund.

3.3.Demand-Supply Interaction

A parking lot's performance indicators, such as turnover rate, occupancy and parking stall search time, are the outcomes of the demand-supply interaction. Congestion at a parking lot occurs when the demand exceeds the supply. Two indicators of service or congestion level are lot occupancy and search time. UPOs concern with occupancy as it reflects the percent of stalls that are occupied at any time, which is correlated to the permit sales and thus revenue. Drivers are more concern with search time. Increase in search time may lead to students having to park elsewhere, park illegally, and as a result being late for class. Search time will be discussed in the next sub-section.

On a university campus that has multiple parking lots, the analysis of demand-supply interaction is made more complex by the fact that the parking demand depends on the type of users (students, faculty, staff, visitors), time (hour in a day) and location (of parking lots). The supply may also depend on the time and location (by policies that determine who are permitted to park at certain lots at a certain time). Therefore, the parking congestion on university campuses is a spatial and temporal problem, so are its solutions.

3.4.Search Time

Search time for an empty parking stall, or simply “search time” may be defined as the time a vehicle takes to travel from the main entrance of a campus until it is parked legally in a stall. The time spent by a vehicle circulating around a campus road network and in a parking lot not only causes traffic congestion but also increase emissions. Efficient parking management will help to reduce the unnecessary congestion and emissions.

[Shoup \(2006\)](#) shared his findings of 16 different studies for congested downtown areas around the world. He concluded that, on average, drivers spent 8.1 minutes searching for an available parking stall. No such study has been performed for the university campus.

[Guo et al. \(2013\)](#) modeled the parking stall search process in an agent-based modeling and simulation (ABMS) paradigm based on the drivers' optimistic and pessimistic attitudes with respect to availability of the parking stalls. The University of Buffalo's north campus was used as a case study to illustrate the development, validation, and application of the ABMS model. The authors quantified the environmental effects associated with parking search and estimated that 120 gallons of gasoline are wasted every hour in the parking search process.

3.5.Zoning

A university has many parking lots spread across the campus. The parking lots are usually identified by numbers and types of permits vehicles are allowed to park. This practice is called zoning. In managing a limited supply of parking lots (each has a finite stall capacity), zoning and assigning permits to zones is a key solution to improve parking efficiency ([Zhang et al. 2011](#)). UPOs generally divide parking lots into different zones according to the proximity to the campus core. In this zoning system, permit holders can only park at the assigned lots written on their permits. Faculty and staff are usually given the option to purchase permits at higher prices to park

at lots in the campus core, while students are given parking lots at the fringe of the campus, with permits sold to them at lower prices.

3.6. Permit Price

The UPO's income comes from three sources: permit sales, visitors parking and citations. Permit sales are the major source of income for UPOs. For examples, Texas A&M University and George Mason University rely on permit sales to raise 58% of the UPO's income (TAMU 2018, GMU 2018). At California State University at Long Beach, this income proportion increases to 75% (CSULB 2018). At Texas Tech University this fraction is even higher, at 80% (TTU 2018). George Mason University, the UPO's annual revenue was \$17.3 million in 2016, of which \$10.3 million comes from the permit sales, \$3 million from visitor parking and \$0.7 million is from the citations. Another example is California State University at Long Beach. In the academic year 2016-17, its UPO has a total income of \$11.0 million, in which \$8.3 million was from the permit sales and visitors. At Texas Tech University, in 2016, 80% of the \$6.4 million total revenue came from permit sales and visitor payments.

UPOs have been using permit price as a tool to manage the parking demand. However, they are also trying to maximize their incomes. It is very important for UPOs to set the permit prices to keep a balance between raising revenue from permit sales and driving away parking demand. Gurbuz et al. (2018) fitted a Tobit regression model that predicts the “base price” of student parking permit in a university campus, for UPOs to benchmark their permit prices. The model is:

$$\hat{Y}_2 = 154.71 X_2 + 2.98 X_7 - 293.08 X_{10} + 2187.71 X_{13} - 516.81 X_{17} \quad (3)$$

The independent variables are:

X_2 = campus setting (1 for urban setting, 0 for suburban setting);

X_7 = cost of living at per diem rate;

X_{10} = proportion of undergraduate students;

X_{13} = faculty/student ratio; and

X_{17} = proportion of students who purchased permits.

3.7. Permit Cost

While a UPO set the price of a permit it puts up for sale, to the student this becomes the cost of parking he/she has to pay. Permit cost is one of the many factors that potentially influence a student's choice of parking lots. The other potential factors are permit cost, distance from the classroom building, lot capacity, shelter or shuttle service. Based on the responses for an internet-based transportation survey, Chaniotakis and Pel (2015) concluded that parking cost was the most important factor in determining parking location decision, followed by walking distances and availability of parking stalls upon arrival.

3.8. Class Schedule

In an academic semester, the demand for parking fluctuates with time-of-the-day and day-of-the-week. In a university campus, the parking demand of students depends heavily on their class

schedule. Commuting students tend to arrive at campus 30 minutes or earlier before the first class of the day and leave within 30 minutes after the last class. Therefore, class schedule has an impact on the arrival rates and departure rates of vehicles at parking lots. It appears that class schedule has the potential to be used as a tool to ease parking congestion problem on campus. Examples are stagger class start and end times, and avoid scheduling too many large classes to start and end at the same time. However, for a university with large enrollment and limited classrooms, efficient use of classroom space usually takes priority than parking congestion. There are many constraints that limit the use of the class schedule to solve parking congestion on campus. [Moradkhany et al. \(2015\)](#) showed that with proper class schedule adjustments, the parking demand at University of Akron, Ohio could be distributed more evenly over time, resulting in an average saving of 20% in search time.

3.9. Availability of Transit

There are two types of transit systems which serve to alter the travel behavior of campus users in two different ways.

The first type of transit system is the campus shuttle bus system. The system provides an alternative form of transportation that brings users from remote parking lots to any point in the campus, thus encourages drivers to park further from the campus core. This “park-and-ride” spreads the spatial parking demand. For the campus shuttle bus system to work well to support the campus parking system, its routes and service headways must meet the demand, especially during the morning peak hour.

The second type of transit system is the city’s or county’s bus system. This type of transit system provides an alternative for users to switch transportation mode in their daily commutes from home to campus, therefore reduce the parking demand on campus. For this transportation option to be attractive, the city’s or county’s bus system must be integrated with the campus transportation system, by (i) having routes that pass through the campus; and/or (ii) having coordinated transfer points and service schedule for riders to easily transfer to the campus shuttle bus system to reach their final destinations. In addition, the UPOs must work with the city’s or county’s transit service provider to give incentives for students to use transit instead of driving to campus.

[Kaplan \(2015\)](#) found in his survey at Kent State University that students did not favor the sustainable transportation (transit, bicycle, and walking). One important reason that discourages sustainable transportation activities is the absence of supporting infrastructure. According to the survey results conducted in Villanova University, [Mctish et al. \(2016\)](#) suggested that in order to discourage students from driving alone to campus, the university should provide a campus shuttle bus program, work with the city to provide discounted tickets for public bus and train (mass transit or metro) users, give incentives for carpools and encourage bicycle use.

The Federal Highway Administration ([FHWA 2004](#)) reported that the commuters tended to change from the driving-alone mode when they are provided with detailed information about location, routes, timing and the other critical information of other alternative modes. A survey conducted at University of California at Berkeley revealed that the quality of transit service and trip time both had significant effect on student’s mode choice ([Riggs 2014](#)). The same survey also found that

free or discounted public transit programs significantly reduced the single student-driver trip to the campus. [Proulx et al. \(2014\)](#) conducted another survey at University of California at Berkeley. The discrete choice models developed from the survey data showed that the drive-alone mode share could be reduced by 3% with a combination of increases in parking price and the transit subsidies. The University of Colorado avoided the construction of 2,000 new parking stalls by a program that gave students free rides on transit and light rail services. The program successfully caused 41% of the students who drove alone to switch to use the public transportation systems ([Kenney 2004](#)). [Sultana \(2015\)](#) surveyed 2,000 undergraduate students at University of North Carolina at Greensboro. She found that a student's decision to or not to purchase a permit was mainly determined by the student's car ownership, car use habits, faster mobility needs, and distance of daily commute, but not environmental concerns.

4. PARKING DEMAND AND SUPPLY MANAGEMENT ON UNIVERSITY CAMPUSES

This chapter reviews the parking demand and supply management at four selected universities: Cornell University (Cornell), The University of Texas at El Paso (UTEP), University of California at Davis (UCD) and University of South Florida (USF). This chapter consists of five sections. Each of the first four sections describes the detailed parking conditions at one university. The last section makes a comparison among the selected universities.

4.1. Cornell University

4.1.1. General Information

Cornell University (Cornell) is a private university founded by Ezra Cornell and Andrew Dickson White in 1865. The campus at Ithaca, New York was opened in 1868. Today, the campus has 608 buildings on more than 4,000 acres. Although Cornell University has other campuses, this report focuses on the main campus at Ithaca, New York. The total population of the university including faculty and staff was 32,949 in Fall 2017. The detailed population information is listed in [Table 1](#).

Table 1 - Cornell University population (Fall 2017)

Faculty and Staff	
Number of Faculty	1,650
Number of Staff	8,283
Student Enrollment	
Undergraduate	14,907
Graduate	8,109
Total Student	23,016
Total University	32,949

Cornell's Ithaca campus is located in a rural setting in the City of Ithaca, New York. In the last census in 2010, the city had a population of 19,930. This city population did not include the university population. Ithaca experiences a moderate climate. Winters are long and cold, while summers are warm and humid with comfortable temperatures. The average temperature in Ithaca goes down to 17°F in January and up to 82°F in July. Ithaca receives an annual average of 2.68 inches of precipitation ([TWC 2018](#)).

Cornell is a private university. The typical tuition for a full-time undergraduate student in the 2017-2018 academic year was declared at \$54,584 ([Cornell 2018](#)). Other required fees were \$604. The estimated room and board on campus was \$14,816.

At Cornell, 54% of the undergraduate students live in college-owned, operated or affiliated housing. The rest of the students (46%) are commuter students ([Cornell 2018](#)). In order to define and compare the living expenses, the authors of this report used the General Service

Administration (GSA) per diem rate (lodging, meals and incidental expenses per day), averaged over 12 months in the fiscal year 2018. The per diem rates for Ithaca for one-night stay was \$122 for lodging plus \$59 for meals and incidental expenses. This sum up to the total daily expenses of \$181. On the other hand, according to Sperling's Best Places indices ([Bestplaces.net](https://www.bestplaces.net)), the United States average living index is assigned as 100. Ithaca's overall cost of living index is 112 and the state average of New York is 122.

4.1.2. Parking Information

Cornell's Department of Transportation and Delivery Services (TDS) is responsible for campus parking and all commuter programs including bus services, carpool, bicycle, rideshare, etc. Cornell's campus has a total of 4,040 parking stalls for students and the average student/stall ratio is nearly 5.7. The limited parking facility for students is managed with different demand and supply management strategies. Cornell's parking management practice is accredited by the Accreditation for Parking Organization (APO) in 2015. APO is a certification program developed by the International Parking Institute ([IPI 2015](#)). APO's certification program recognizes the best practices in parking management and operations, customer service, professional development, sustainability, safety, and security.

Campus parking at Cornell is controlled by permits. Since parking stalls are very limited, permits are sold to eligible students on first-come, first served basis. All the permits are annual passes. Student permits are sold or renewed through an online parking portal, while employees must go to the TDS office in person to purchase or renew permits. There are no semester based permits but any permit holder can return his/her permit and get a refund.

The parking lots in Cornell campus are denoted by single or double alphabet codes such as A, B, D, J, R, O, SC, ND, WD. In addition, one or several lots are grouped to form areas named Central, Mid, Perimeter, Outer, Commuter Parking, and Resident Parking (see [Figures 1 and 2](#)). Permits are sold, and permissions to park, are based on the lots and/or areas. From [Figures 1 and 2](#), one can observe that Cornell employees have the option to purchase permits to park in the Central, Mid, Perimeter and Outer areas; while student commuters are restricted to the Perimeter and Outer areas. At Cornell, students may park in:

- A lot – which is in the Outer area in the north side of the campus;

- B lot – which is at the southeast Perimeter of the campus;

- SC lots – which are multiple lots that spread across the south Perimeter of the campus; and

- Resident lots – which are at the north Perimeter of the campus.

Students may purchase three types of parking permits at B, SC, and Resident. B commuter permits, with an annual fee of \$359.85, are valid for parking in B lot all the time and in A (outer) lot after 2:30 p.m. SC commuter permits, with an annual fee of \$752.86 are valid in SC lots in all times and in A lots after 2:30 p.m. Resident permits are only valid in their designated areas in all time and A lots after 2:30 p.m. The annual permit price for the resident permits (FH, ND, WD, SW) is fixed at \$752.86 ([Cornell 2018](#)). It appears that, in Cornell, parking behavior of students changes at 2:30 p.m. and the permission to park in different lots have been designed for this.

Table 2 - Student parking permits at Cornell University

Permit type	Annual price	Lots permitted to park 24 hours/day	Lots permitted to park after 2:30 p.m.
B	\$359.85	B	A
SC	\$752.86	SC	A
Resident	\$752.86	FH, ND, WD, SW	A

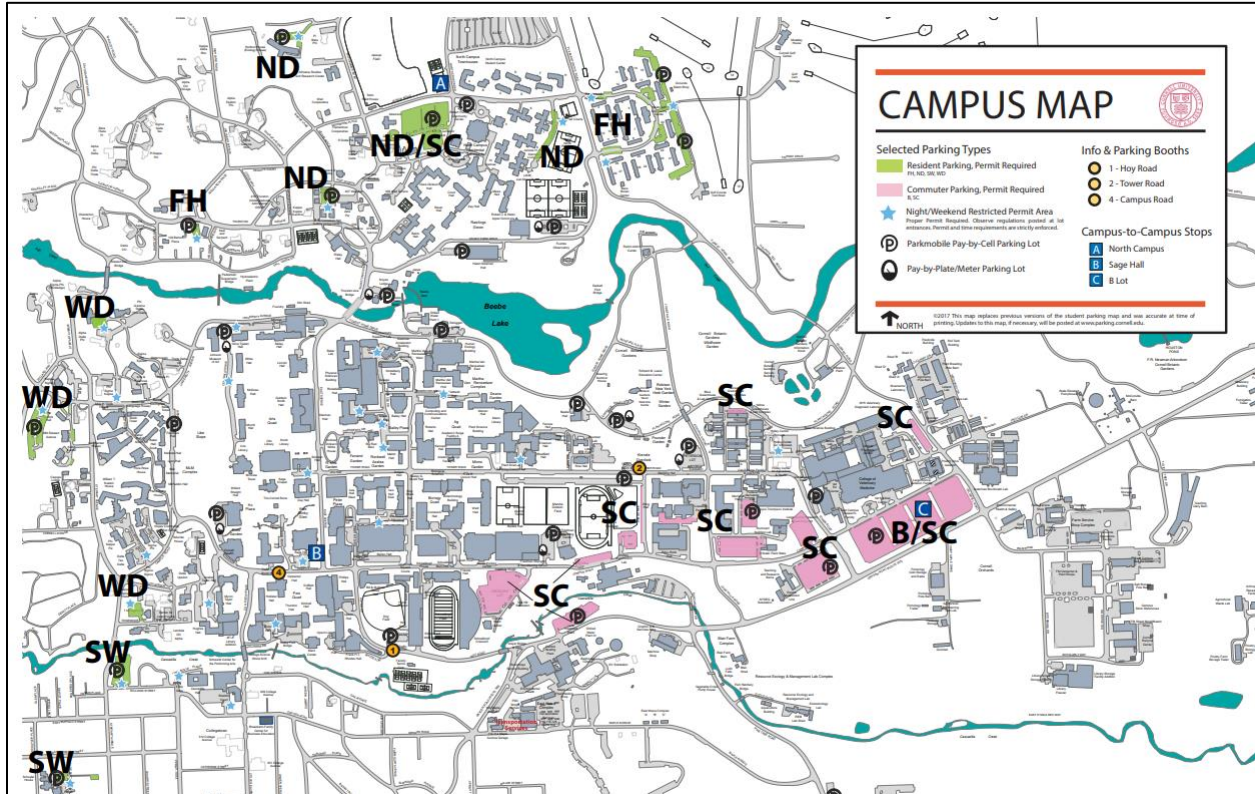


Figure 1 - Student parking lots at Cornell University
Source: Cornell University Facilities and Campus Services

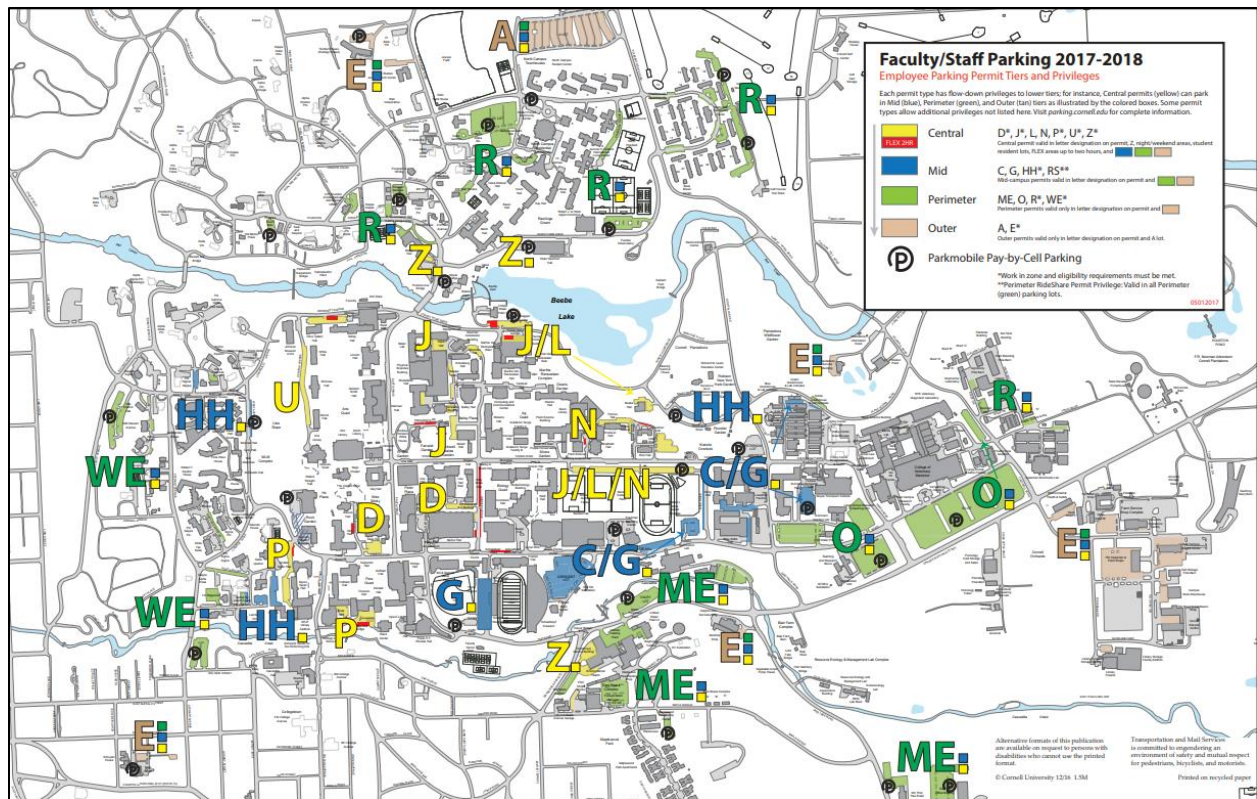


Figure 2 – Faculty and staff parking lots at Cornell University
 Source: Cornell University Facilities and Campus Services

4.1.3.Sustainability

Cornell's TDS offers a range of transit options for the commuters. The university has a close partnership with Tompkins Consolidated Area Transit (TCAT) Inc. TCAT serves the entire Tompkins County where Ithaca is located. Students on their first year of study at Cornell can ride the bus free of charge anytime for one year. From the second year of study and beyond, they can ride the buses for free after 6 p.m. on weekdays and anytime at weekends.

Cornell employees can also join a carpool program. This program requires employees to carpool to campus at least 3 days a week. Members of this carpool program benefit from the discounted parking fees and can get occasional use and single day parking permits.

Cycling in Cornell is very common. Cornell campus has many bicycle lanes and bicycle trails. All the bikes should be registered through the online university portal.

There are three Electric Vehicle (EV) charging stations in two parking garages. EV vehicle owners should have the regular parking permits to enter, park and use the charging stations. Moreover, there are several stalls inside the parking garages reserved for the low emission vehicles. Those stalls are specially signed and painted to be used by the vehicles which meet the Green Building Council standards.

4.1.4.ITS in Parking and Transportation

Cornell also provides paid visitor parking stalls all over the campus. One of the alternative for paying for visitor (short-term) parking is the Parkmobile smartphone application (see [Figure 3](#)). This application allows visitors to pay parking fees while parking at four designated lots.

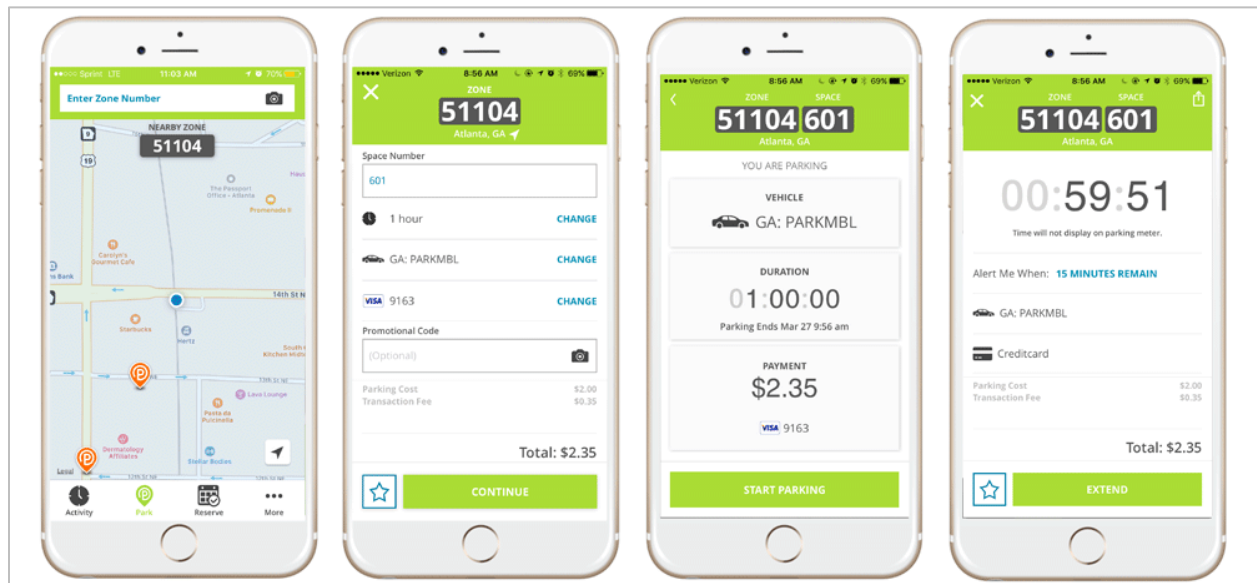


Figure 3 – Parkmobile smartphone application
Source: Apple Store

4.2. The University of Texas at El Paso

4.2.1.General Information

The University of Texas at El Paso (UTEP) is a public university founded in 1914. UTEP is one of the institutions in The University of Texas System. The total population of the University including faculty and staff is 27,676 ([UTEP 2018](#)). The detailed population information that is collected from the university's web page is in [Table 3](#).

Table 3 - The University of Texas at El Paso population (Fall 2017)

Faculty and Staff	
Number of Faculty	1,149
Number of Staff	1,449
Student Enrollment	
Undergraduate	21,341
Graduate	3,737
Total Student	25,078
Total University	27,676

UTEP campus is located in an urban setting close to the downtown of the City of El Paso, on 420 acres of land. El Paso is at the far western corner of Texas, the neighboring city of Las Cruces, New Mexico and Juarez, Mexico. In the 2010 census, the City of El Paso had a population of 649,121. Including the neighboring city Juarez and Las Cruces, the metropolitan area has more than 2 million residents. El Paso experiences a transitional climate between cold and hot desert. Summers are hot and dry, while winters are generally cool with little humidity. Rainfalls mainly occur in summer from July through September and city receives annual average precipitation only 0.81 inches ([TWC 2018](#)). The average temperature goes down to 33°F in December and January and goes up to 96° F in June.

UTEP is a public research university. The typical tuition for a full-time undergraduate student for the full 2017-2018 academic year (30 semester hours) is declared as \$7,651. The books and supplies are estimated at \$1,632 and the other expenses at \$3,382 ([College Data Online College Advisor 2018](#)).

At UTEP, only 4% of all students live in on-campus housing. The rest (96%) are the commuter students. That huge percentage of commuter students is an important indicator of the parking demand. According to [GSA \(2018\)](#), the per diem rate for the city of El Paso for is \$98 per night for lodging and \$59 per day for meals and incidental expenses. Cost of living index of El Paso was calculated as 84 ([Bestplaces.net](#)) based on the overall United States average (100). The state average of Texas is 90.

4.2.2. Parking Information

At UTEP, Parking and Transportation Services (PTS) is responsible for the operation and management of parking and shuttle services. The university has a total of 6,623 parking stalls for students on campus, giving the student/stall ratio of nearly 3.66. For many years, PTS manages parking with zoning and pricing of the permits. The number of permits is set for each parking lot. Parking permits are sold by first come, first served basis. All the permits are sold through the online parking portal and are valid for one year starting August 15. There is no semester based permits but any permit holder can give up the permit any time and get a refund.

Student parking lots at UTEP are grouped into five zones, each with its annual permit fee ([UTEP 2018](#)):

- (1) garages, at \$319.50 per year;
- (2) silver open lots, at \$240.75 per year;
- (3) perimeter lots, at \$188.25 per year;
- (4) remote lots, at \$138.05 per year; and
- (5) resident lots, \$154.10 per year.

On weekdays, after 3:00 p.m. nearly all permit holders are allowed to park at any surface parking lot outside the inner campus. Any other parking permit holders can park at the garages only after 4:00 p.m. Although the inner campus is restricted just for faculty/staff with inner campus permits, all permit holders can park in the inner campus after 5 p.m.

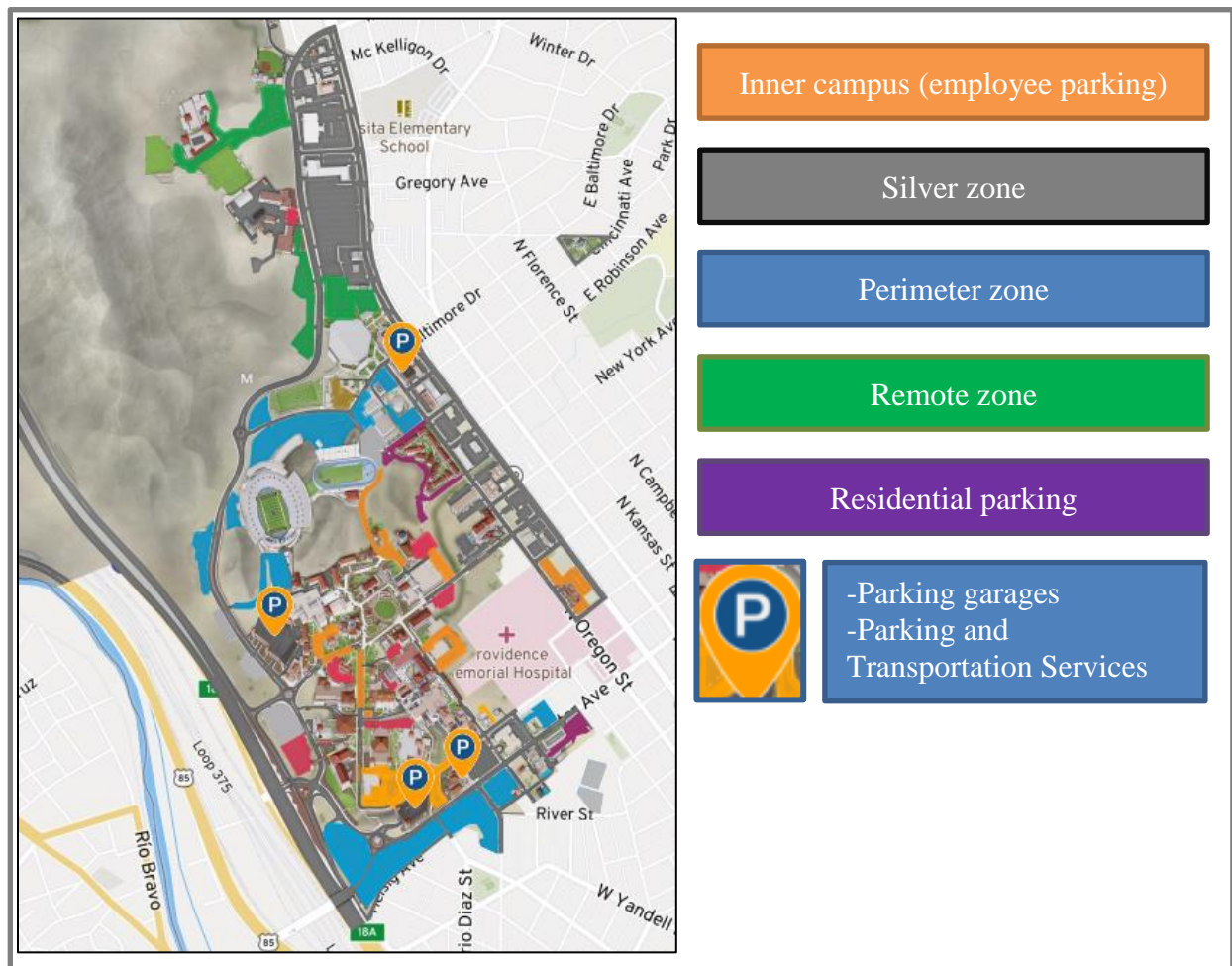


Figure 4 - Parking zones at The University of Texas at El Paso
Source: The University of Texas at El Paso Parking and Transportation Services

There are limited parking options for the visitors. If a visitor wants to park inside the campus, he/she has to stop by an information booth and get permission to go inside the gate, and park at a metered parking stall. Depending on the locations, visitors pay parking fees via the meter or at pay stations by credit card or cash.

4.2.3.Sustainability

UTEP PTS operates campus shuttle bus service called Miner Metro, which are free to all employees, students, and visitors. There are 4 different routes covers all the important locations and parking lots throughout the campus. Real-time locations of the shuttles can be tracked via a smartphone application.

The City of El Paso operates the city's Sun Metro bus transit system. Sun Metro provides students 33% discount over the regular fare. Sun Metro has several routes that pass by Mesa Street and/or Oregon Street just outside the campus. One of the transfer centers (Glory Road Transfer Center) is on the edge of the university boundary.

UTEP also has a carpool program for students and employees. Via an online request form, commuters can connect with others interested in carpooling. In some parking lots, there are designated carpool stalls just for carpool permit holders. Each registered carpool members are given 10-day passes in case they need to drive alone to the campus.

There are seven different locations providing parking spaces designated just for use by the EVs. Some of the stalls are only available for the permit holders but the others are located in the visitor parking lots.

4.2.4.ITS in Parking and Transportation

The UTEP campus has several traffic control gates to limit vehicle access to parking garages, the inner campus and faculty/staff parking lots to relevant permit holders. The remaining surface lots do not have any gate to control or count vehicles at the entrances and exits.

The campus shuttle buses can be tracked real-time through a smartphone application called DoubleMap Bus Tracker (see [Figure 5](#)). This application let users view the bus locations in real time and the predicted time of arrivals at bus stops.

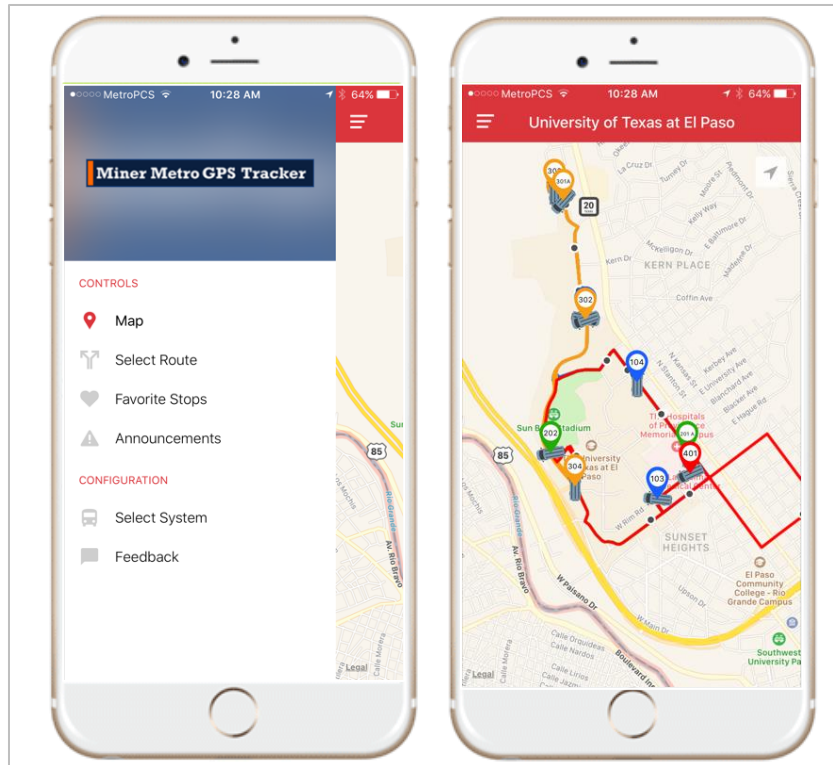


Figure 5 - DoubleMap Bus Tracker smartphone application
Source: The University of Texas at El Paso Parking and Transportation Services

4.3. University of California at Davis

4.3.1. General Information

University of California at Davis (UCD) is a public university and is part of the University of California system. The university is located in Davis, California with a total campus area of 5,300 acres ([UCD 2018](#)). The total population of the university including faculty and staff was 63,504 in Fall 2017. The population and enrollment statistics are summarized in [Table 4](#).

Table 4 - University of California at Davis population (Fall 2017)

Faculty and Staff	
Number of Faculty	2,133
Number of Staff	24,093
Student Enrollment	
Undergraduate	30,145
Graduate	7,133
Total Student	37,278
Total University	63,504

The UCD campus is located on a suburban setting of the City of Davis. Davis is a small city. According to the 2010 census, the population of the city excluding the on-campus residents was 65,622. Rainfalls mainly occur in winters starting from November through March, with annual average precipitation of 1.64 inches ([TWC 2018](#)). The average temperature ranges from 38°F in December and January to 94°F in June.

UCD is a public research university. For a full-time undergraduate student, the tuition fee for the full 2017-2018 academic year (three quarters) was \$14,382. At UCD, 25% of all undergraduate students live on campus. The remaining 75% of undergraduate students are living off campus and commute ([UCD 2018](#)). The per diem rates for Davis was \$117 per night for lodging and \$64 per day for meals and incidental expenses, which sum up to the total daily expenses of \$181. According to Sperling's Best Places indices ([Bestplaces.net](#)), the cost of living index in Davis is 173 where the United States average was assigned as 100. The State of California's average index is 152.

4.3.2. Parking Information

At UCD, campus parking is managed by Transportation Services. Transportation Services responsibilities include permit sales, provide alternatives for commuters, bike registrations, and road construction and repairs. The university campus has a total of 11,368 stalls for the students. With this, the average student/stall ratio is nearly 3.21. Of the 11,368 student stalls, 8,541 stalls are for the commuter students and the rest are for residents ([Gudz et al. 2016](#)). In an average weekday, 85% of the UCD community physically travel to campus. Among them, 30% drive alone. The remaining 70% prefers other alternatives.

UCD Transportation Services manages the parking by zoning and pricing the supply, combined with demand management. Parking lots for commuters are marked as “A” (for staff and faculty), “C” (for students) and “L” zones (for students, staff, and faculty). The locations of “C” and “L” zones are shown in [Figure 6](#). The locations of “A” zones are shown in [Figure 7](#). Parking permits (by zones) can be purchased online or in person at the Transportation Services office. They are sold by the full calendar month, on first come, first served basis. Residents, carpool and vanpool have their own designated lots or stalls. Commuter zone “C” permit costs \$45 per month. On the other hand, a remote commuter zone “L” permit is priced at \$25 per month. The prices for the “A” permit is \$55 per month ([UCD 2018](#)).

To increase the supply of parking space, the Transportation Services practices stack parking in three parking lots. The stack parking program allows vehicles to park in the aisle space within the facility or double park. Drivers who park on the aisle should give the car key to the attendant on duty. Stack parking has increased the capacity of one facility by 120 stalls.

Visitors of UCD has several parking options: (1) purchase a visitor daily parking permit for \$9 from permit dispensers located at visitor parking lot entrances; (2) purchase a booklet of 10 daily visitor permits from the Transportation Services office; (3) loan an EasyPark tablet (essentially an in-vehicle parking meter, see [Figure 8](#)) from the Transportation Services office, and pay by the minutes. The Easypark is an option not found in most universities.

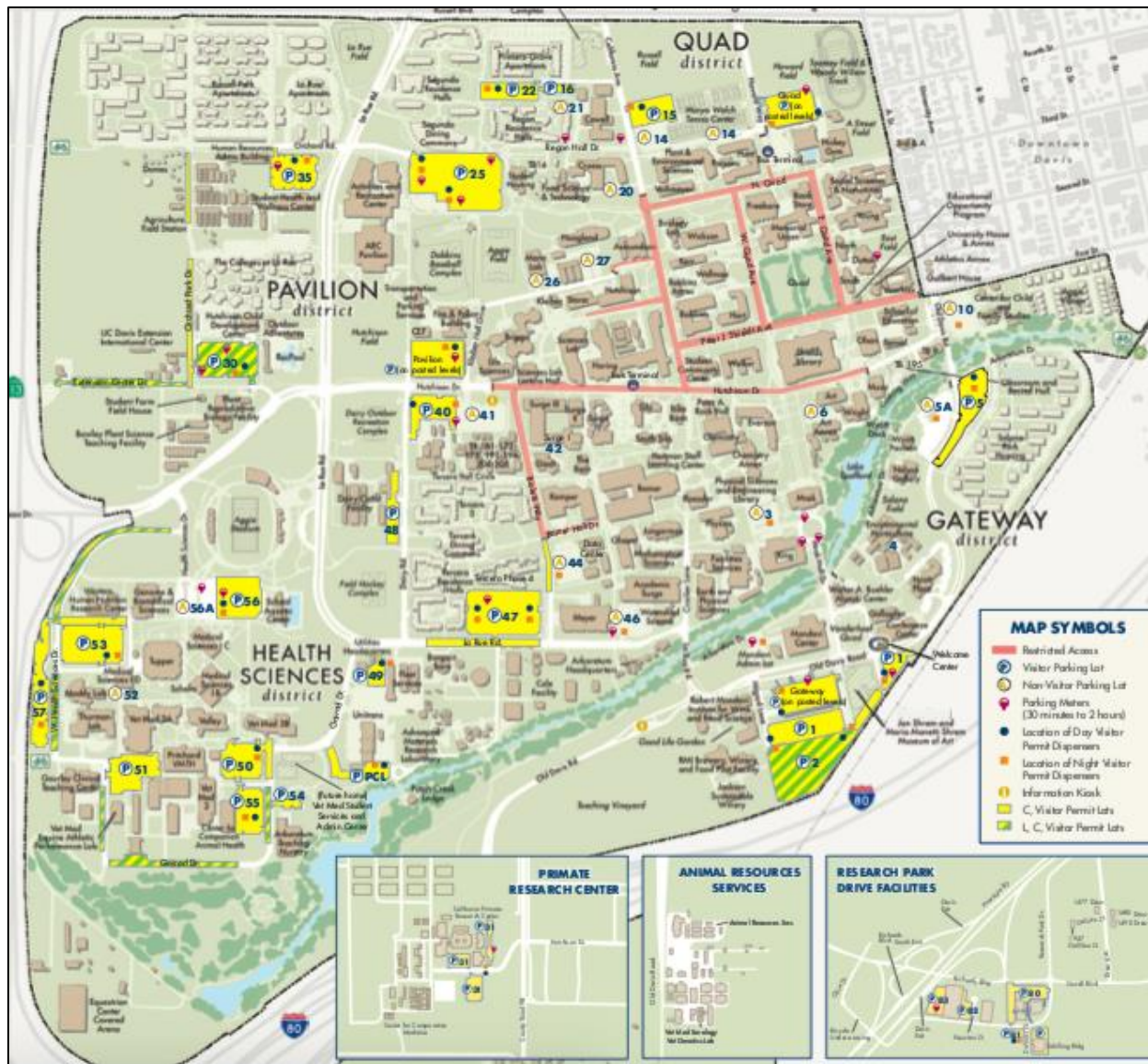


Figure 6 - “C” and “L” parking zones at University of California at Davis
Source: University of California at Davis Transportation Services

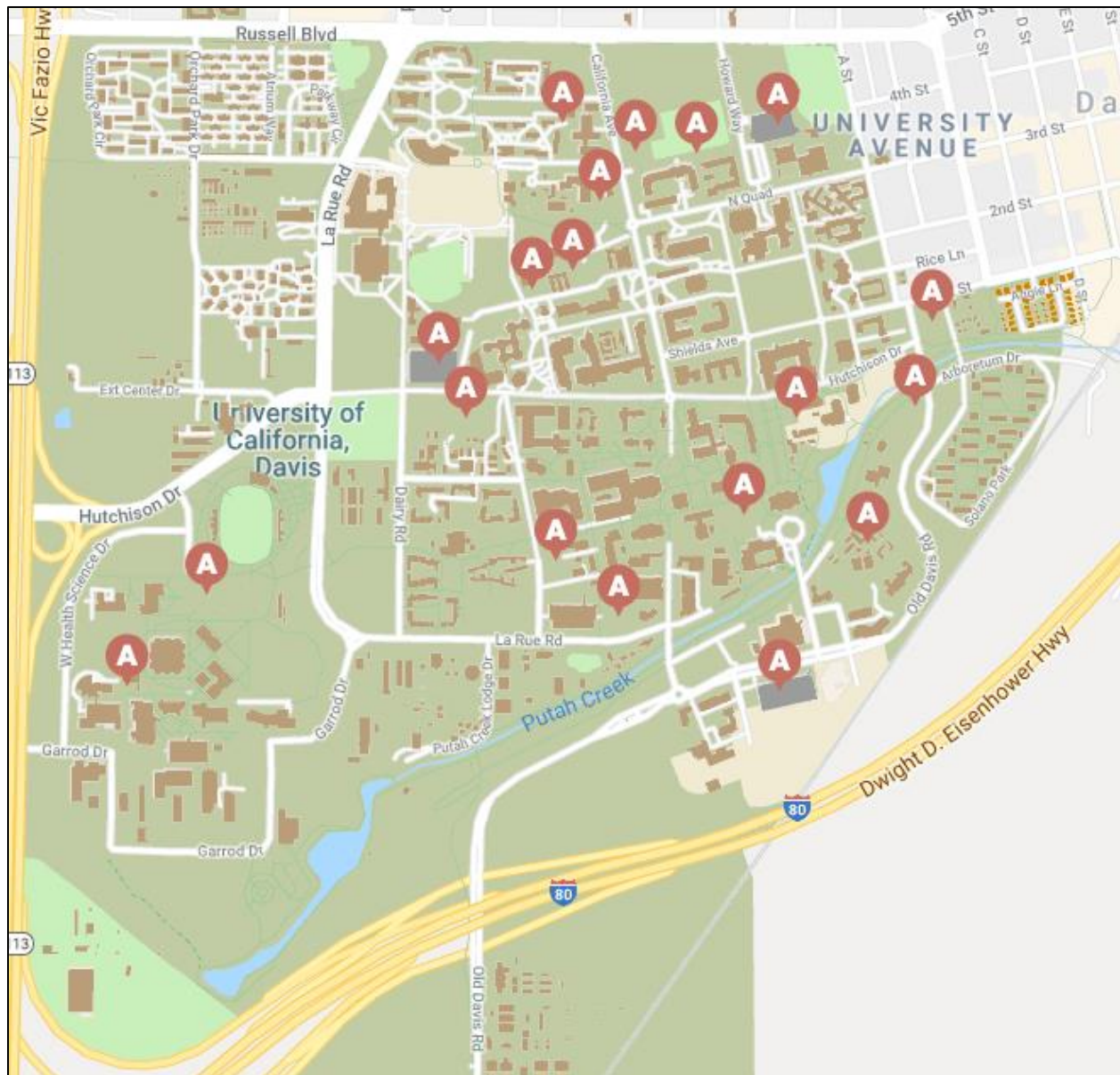


Figure 7 - “A” parking zones at University of California at Davis
Source: University of California at Davis Transportation Services



Figure 8 - EasyPark mobile device
Sources: University of California at Davis Transportation Services

4.3.3.Sustainability

The UCD community is familiar with sustainable transportation alternatives. A transportation survey (Gudz et al. 2016) determined that 37% of the respondents used bicycles, 8% walked or skated, 5% traveled by carpool, 19% rode buses and 1% rode train as their primary modes. They added up to 80% of the UCD population.

GoClub is an integrated program to encourage commuters to choose alternative modes to drive alone (carpool, bike, walk, bus, train). The program is for UCD student, faculty or staff who are not living on campus. GoClub is the collective name of several programs: GoBike, GoWalk, GoCarpool, GoVanpool, GoBus, and GoTrain. GoClub members are, as an incentive, have a chance to win some gifts through the program. Besides, each program has its own incentives for the members. For examples, GoBike members have the opportunity to use the lockers and showers, 20% discount on bike locker rental, discounted rate for the public transit and up to 24 complimentary parking permits. GoWalk members are given complimentary access to the lockers and showers, discounted bus passes and complimentary parking permits. GoBus and GoTrain members are eligible to have discounts for the transit systems and complimentary parking permits.

UCD is one of the universities that majority of the commuters ride bicycles to campus. The City of Davis has a network of bicycle paths that are integrated into the UCD campus transportation plan. UCD is recognized by League of American Bicyclists as a Platinum Level Bicycle Friendly Universities (The League of American Bicyclists 2018).

UCD has a number of parking stalls in almost every parking lot for use by the EVs. Each EV, with a valid campus parking permit, can park in such a stall and charge for up to four hours.

4.3.4.ITS in Parking and Transportation

UCD has its own mobile device called EasyPark (see Figure 8) for visitors to pay the parking fee on campus. Visitors can load money into this “personal parking meter”. By using this device, users are charged only for the time they parked.

4.4. University of South Florida

4.4.1. General Information

University of South Florida (USF) is a public university founded in 1956. The University of South Florida system includes three separate institutions: USF Tampa, USF St. Petersburg and USF Sarasota Manatee. This report focuses on the USF main campus in Tampa. For the rest of this report, USF Tampa is referred to simply as USF. This campus has a total area of 1,550 acres. The total number of students at USF is 43,542 (USF 2018). The total population of the University including faculty and staff is 52,787. Detailed population information that is collected from the university's web page (USF 2018) is listed in Table 5.

Table 5 - University of South Florida population (Fall 2017)

Faculty and Staff	
Number of Faculty	3,536
Number of Staff	5,709
Student Enrollment	
Undergraduate	30,984
Graduate	12,558
Total Student	43,542
Total University	52,787

USF campus is located in the City of Tampa, Florida. The city of Tampa has a population of 335,709 in the 2010 census, is the largest city in the Tampa Bay area. Tampa has a humid subtropical climate zone and shows some characteristics of a tropical climate. Summers are hot and humid with thunderstorms while winters are generally dry and mild. High rainfalls mainly occur in summers starting from June to September. The annual average precipitation the city receives is 3.87 inches (TWC 2018). The average low temperature goes down to 52°F in January and up to 90°F in June, July and August.

USF is a public research university with a typical tuition fee of \$6,336 for a full-time undergraduate student in the 2018-2019 academic year (30 semester hours). At USF, 18% of all undergraduate students live on campus. The remaining 82% of undergraduate students are living off campus (USF 2018). Per diem rates for Tampa is \$129 per night for lodging and \$54 per day for meals and incidental expenses (GSA 2018). This sums up to a daily allowance of \$183. According to Sperling's Best Places indices (Bestplaces.net), Tampa's overall cost of living index is 94, which is lower than the national average of 100 and the State of Florida's average of 101.

4.4.2. Parking Information

Parking and Transportation Services (PTS) is the department in USF responsible for the management of the campus transit systems and all parking facilities. The USF campus has 45

parking lots and six parking structures. According to the most recent master plan (USF 2015), the total parking capacity (number of stalls) was 20,840, in which 11,151 were for students. The students/stall ratio was nearly 3.90. According to the USF master plan, Tuesday had the highest overall lot occupancy with 81% utilization.

A transportation survey was conducted at USF campus in 2014 (CUTR 2015). This online survey had 2,821 participants. The results showed that 82.5% of faculty, 86.2% of staff and 71.1% of all students prefer to drive to USF alone.

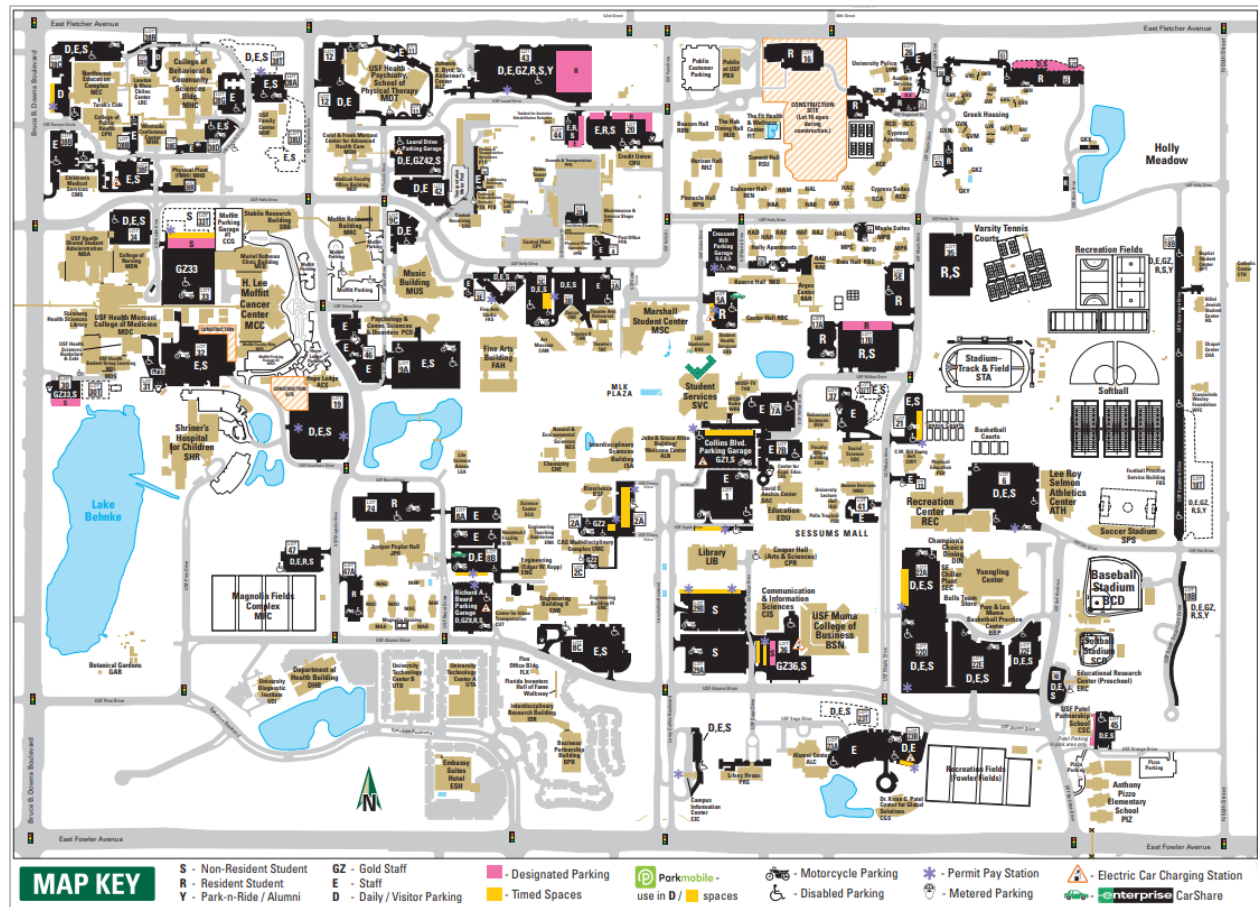


Figure 9 - Parking zones at University of South Florida
Source: University of South Florida Parking and Transportation Services

Figure 9 displays the parking map of the USF campus. At USF, there are three types of annual permits for students. Table 6 summarizes the uses of these permits. The permits are sold to students via an online portal.

Table 6 - Student parking permits at University of South Florida

Permit type	Users	Annual fee	Ability to park outside designated lot
S	Commuter students	\$183	After 5:30 p.m.
R	Residents	\$226	After 5:30 p.m.
Y	Park-and-ride or alumni	\$59	After 9:00 p.m. Monday to Thursday; after 5:30 p.m. on Friday

USF issues four different types of employee parking permits: GZ, E, D, and Y. They represent Gold Zone, Employees, reserved and park-and-ride. They are priced at \$450, \$270, \$1,076, and \$59 per year. All the permits for USF employees can be purchased through the online parking portal.

Visitors to USF campus can purchase a one-day visitor parking permit through university online services. Visitors can also use this permit to get free rides on campus shuttle buses. Visitors can stop by the PTS building and purchase the daily scratch-off permits. Another option is to park in stalls that allowed payment via a pay station. In addition, Parkmobile, a mobile smartphone application, is an alternative payment option.

4.4.3.Sustainability

USF received “Gold” Sustainability Tracking, Assessment and Rating (STAR) in 2018 ([STAR 2018](#)). The STAR report indicated that, 55% of USF students prefer to drive alone to campus, 15% of them prefer to walk, bike or use other means of non-motorized modes, 18% prefer to vanpool or carpool, 11% take campus shuttle or public transportation, while 0.9% use a motorcycle, scooter or moped.

USF’s campus shuttle bus system is known as the Bull Runner. It is free for student, faculty, and staff. Visitors can ride the Bull Runner for free if they are accompanied by someone with a USF ID card or have parking receipts from one of the pay stations. Real-time locations of the shuttles are being tracked and disseminated with a smartphone application. The county’s transit service is provided by the Hillsborough Area Regional Transit Authority (HART). USF students showing valid USF IDs can have free rides on several bus routes offered by HART; while faculty and staff pay a discounted fare of \$0.50 per ride. HART and USF shuttle service connections are available at the campus transit center.

To encourage carpool, USF has parking stalls reserved for vehicles participating in the carpool program. Carpool program participants also receive three one-day individual parking permits per semester.

The campus has five EV charging stations in three different parking locations. EV owners with valid USF parking permits can enjoy free charging of up to 4 hours.

To increase the rate of bicycle use among commuters, USF puts some efforts to develop infrastructure for the bicyclists. The League of American Bicyclists recognized USF with a Silver award among the Bicycle Friendly Universities ([League of American Bicyclists 2018](#)).

4.4.4.ITS in Parking and Transportation

USF's parking portal is designed for students, faculty, staff, and visitors to purchase permits. Visitors can print out the permit directly instead of picking up permits from the PTS office. USF has a mobile smartphone application called MyUSF. Examples of MyUSF screenshots are shown in [Figure 10](#). This application provides students and employees access to key university resources online, including real-time information of shuttle buses, locations of parking lots, pay stations, bike lanes and racks, EV charging stations, and bus stops. MyUSF has a trip planner feature which assists users in planning trips to and from the campus buildings and some areas around the campus, offering transportation alternatives and trip times.

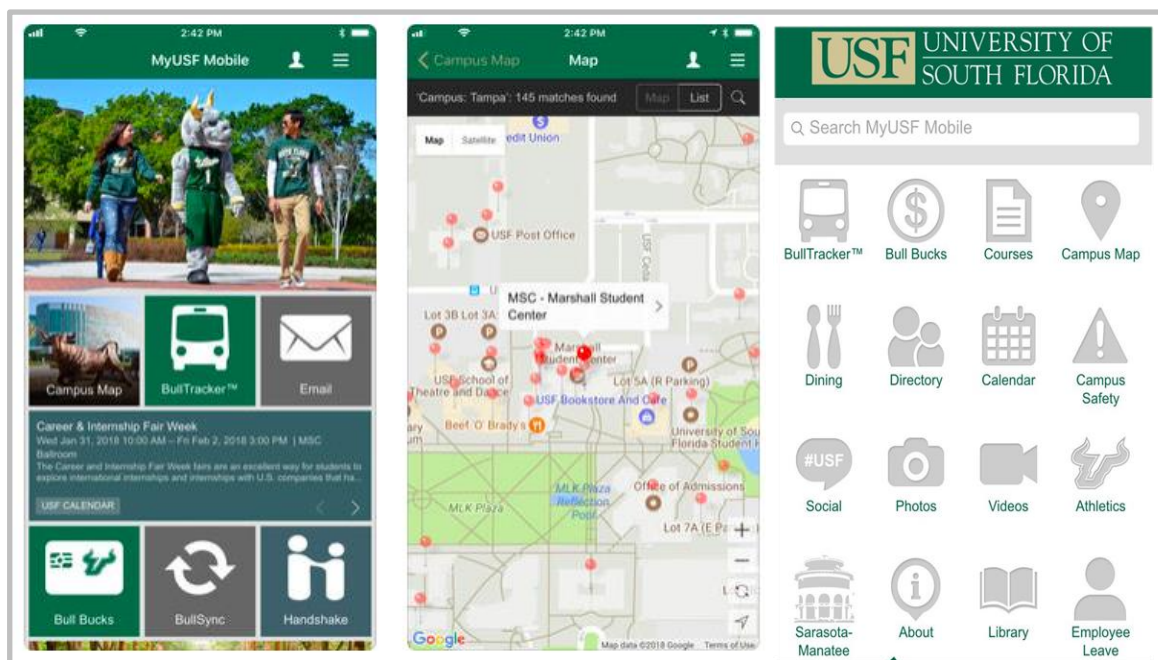


Figure 10 - MyUSF smartphone application
Source: Apple Store

4.5. Comparison of the Universities

The information collected from Cornell, UTEP, UCD, and USF are compared in [Tables 7 and 8](#). Cornell University has the highest student/stall ratio. On the other hand, Cornell provides 46% of its undergraduate students housing on campus. This on-campus student resident rate is the highest among the four universities. This policy reduces Cornell's commuter students parking demand. UTEP has the second lowest student/stall ratio. However, UTEP is an urban campus with 96% of its students commutes to campus. This creates traffic and parking congestion problems before and after classes. UCD has programs to encourage alternative means of transportation, to promote sustainability. USF's strength in parking and transportation management is the use of ITS technologies. Each university still has the potential to improve their parking and transportation applications. Chapter 5 is designed to share some important innovative applications which propose solutions for parking problems at universities.

Table 7 - Comparison of demographics and infrastructure conditions

Attributes	Description	Cornell	UTEP	UCD	USF
Type of university	Public or Private	Private	Public	Public	Public
Campus setting	Rural, Suburban or Urban	Rural	Urban	Suburban	Urban
City population	Excluding the university population	30,014	649,133	65,622	335,709
Campus area	In acres	4,000	420	5,300	1,550
Temperature range	Ave. low – ave. high	17°F -82 °F	33°F -96 °F	38°F -94 °F	52°F -90 °F
Cost of Living	GSA per diem	\$181	\$157	\$181	\$183
Tuition fees	Undergraduate, Fall to Spring	\$54,584	\$7,651	\$14,382	\$6,336
Undergraduate student population		14,907	21,341	30,145	30,984
Graduate student population		8,109	3,737	7,133	12,558
Student population	Total no. of students	23,016	25,078	37,278	43,542
Faculty population		1,650	1,149	2,133	3,536
Staff population		8,283	1,449	24,093	5,709
Total university population		32,949	27,676	63,504	52,787
Percent of commuter students	Commuter students / Total students	54%	96%	75%	82%
No. of parking stalls for students		4,040	6,623	11,368	11,151
Student/stall ratio	Total student population/no. of student parking stalls	5.70	3.66	3.28	3.90
No. of student permit options	No. of zones & permit prices for students	3	5	3	3
Annual permit price	Lowest to highest, 12 months	\$360-\$753	\$138-\$320	\$300-\$540	\$59-\$226

Table 8 - Comparison of sustainability practices and ITS applications

Attributes	Description	Cornell	UTEP	UCD	USF
Sustainability	Practices to reduce environmental impacts	Free or discounted county transit	Free campus shuttle and discounted city transit	Integrated commuter club for carpool, bicycle, transit, train, etc	Free campus shuttle and county transit
		Carpool option	Carpool option	Carpool option	Carpool option
		EV charging stations and parking	EV charging stations and parking	EV charging stations and parking	EV charging stations and parking
				Platinum level in Bicycle League	Silver level in Bicycle League
ITS applications		Parking portal	Parking portal	Parking portal	Parking portal
		Visitor parking payment with Parkmobile	License plate recognition to assist parking enforcement	Visitor pay by EasyPark	MyUSF
		Real-time transit bus tracking	Real-time shuttle bus tracking		Real-time shuttle bus and transit bus tracking

5. INNOVATIVE SOLUTIONS

5.1. Chapter Introduction

Intelligent Transportation Systems (ITS) is gaining popularity as a solution to solve the parking congestion problem. According to the results of a survey conducted by the International Parking Institute (IPI) in 2015 ([IPI 2015](#)), four of the top five emerging trends in parking were related to ITS. They are:

- Innovative technologies to improve access control and payment automation;
- Mobile applications;
- Electronic payment; and
- Real-time communication of pricing and availability to mobile/smartphones.

In another survey, [Krueger \(2008\)](#) found that the use of emerging technology in managing parking problem on campuses was becoming popular, and the GPS-based ITS applications were among the most popular implementations. [Teodorović and Lucic \(2006\)](#) stated that navigation guidance systems increased the probability of finding available parking stalls that decrease the total amount of vehicle-miles traveled, the average search time, energy consumption and air pollution.

Parking management is very complicated because it needs to satisfy different users: faculty, staff, students, and visitors. The management objectives may be to maximize the revenue and/or minimize complaints. Parking on university campuses is generally managed by the UPOs. But there are some campuses where the university police departments are in charge of parking. Michigan State University, Brigham Young University, California State University at Northridge, Central Michigan University, Southeastern Louisiana University, Louisiana Tech University are a few examples. On the other hand, at Ohio State University, California State University at East Bay and Eastern Michigan University, private companies have partnerships with the university and they are responsible for the management and operations of parking facilities.

UPOs are generally self-funded which makes the business model more complicated. Ideally, a UPO's revenue should be compatible with its expenses. For example, at California State University at Long Beach, the total revenue from parking in 2017 was around \$11million (75% coming from permit sales, 7% from events, 7% from citations, and the remaining 11% from others) ([CSULB 2017](#)). At Texas Tech University, the total revenue in 2016 was \$6.3 million in which 80% comes from permit sales and citations ([TTU 2017](#)). George Mason University's annual parking budget was \$17.3 million in 2015, with \$10 million of it came from permit sales, \$3 million from visitors ([GMU 2015](#)). Texas A&M University received \$14.7 million from permit sales in 2017 and this was 58% of the annual parking revenue ([TAMU 2018](#)). Although those numbers seem huge incomes relative to other universities, they barely balanced the annual expenses. Moreover, many universities are expected to build new multi-story infrastructures for parking. University of Massachusetts at Boston has just built a new parking garage that costs \$70 million ([2018](#)).

The previous chapter of this report compares four universities' campus characteristics, parking, sustainable transportation options, and ITS applications in parking. This chapter surveyed innovative parking management practices in more than 300 universities that have student population of over 10,000. This part of the report shares innovative solutions including ITS

applications in parking. The innovative solutions are divided into seven components: (1) zoning; (2) permit sales and pricing; (3) access control; (4) visitor payment; (5) data collection and guidance; (6) enforcement; (7) multimodal integration.

5.2.Zoning

UPOs of most universities group the stalls and lots into zones and charge different prices for stalls in the different zones. In general, zoning and the permit prices are based on the distance from the core area of the campus. The remaining parts of this section discuss different approaches in zoning the parking stalls and lots.

5.2.1.Free remote parking

Commuters tend to park closer to the campus core to reduce their time to reach their final destinations. UPOs generally set higher prices for the parking lots closer to the campus core and lower prices for the lots further from the core. For example, at California State University at Fullerton, the permit price for remote parking lots is 70% lower from the regular price. This helps to keep some vehicles outside the inner campus. To encourage parking outside the central area, some universities (such as University of North Texas, Iowa State University, University of Michigan at Ann Arbor, Pennsylvania State University, University of Nevada at Las Vegas, University of Oklahoma, Boise State University, University of California at Riverside, New Mexico State University, Emory University, University of Vermont, Massachusetts Institute of Technology, etc.) allow commuter students or employees to park at remote zones (also known as outer zones or satellite zones) for free. To make parking at remote zones more convenient, UPOs should provide shuttle services to transport commuters between the lots and the center part of the campus.

5.2.2.Overflow lots

Since the parking behavior (arrival and departure times) of commuter students is directly related to their class schedules, UPOs should expect higher turnover rates for campus parking compared to staff parking. On the other hand, student and faculty parking is not as certain (predictable) as staff parking. To keep the parking lots operating close to their capacities, UPOs tend to sell more permits than the number of stalls. This practice sometimes produces higher parking demand than the number of available stalls. When the stalls are almost fully occupied, drivers start to look for a spot and circulate within the parking lot. Having a parking permit for the assigned lot without an available spot to park makes a student driver feels frustrated and may cause him/her to be late for classes. To solve this problem, some universities assign overflow lots for the permit owners. When a parking lot is full, permit owners are allowed to park in the overflow parking lots. For example, at University of Washington and University of Maryland, each lot is linked with an overflow lot. Permit holders know where to park next when the permitted parking lot is full. The need for an overflow lot arises from overselling of permits. This practice is similar to the overbooking of seats practiced by airlines. The difference is the ways users are handled. For air travel, airlines give compensations (typically cash credit) to affected passengers, in addition to arranging for an alternate flight. For parking on campus, universities typically do nothing, or at most give users an

alternate lot (overflow lot), which very often is also fully occupied. There is no compensation at all to university students.

5.2.3.Zones based on seniority

Universities usually zone parking lots by the lots' proximity to the center core of the campus. The permit price for a zone nearer to the campus core is higher than the permit price for a zone further from the campus core. This zoning arrangement forces student commuters to pay more for permits if they want the convenience of parking closer to their classrooms.

Some universities have a different approach. Instead of offering permits for sale at different prices, they assign parking lots to students by seniority. For example, at Kent State University, although all commuter students are paying the same annual permit price, graduates have more options to park on campus. Undergraduate students are divided into four different classifications (0-29 credit hours, 30-59 credit hours, 60-89 credit hours, 90 credit hours or more). Based on the classification, undergraduate students are limited by the zones in which they are allowed to purchase the parking permits.

5.2.4.Underutilized parking

In 2017, Harvard University introduced a new concept in university parking called “underutilized parking”. This is an option for all employees and students who are not parking the whole day for five days a week. One parking facility is designated for the underutilized parking permit holders. The following underutilized parking permit options are available: morning, afternoon, three-day per week and after 3:00 p.m. A commuter may select the morning option if he/she comes to the campus in the mornings only, or if he comes to school less than three days in a week, he/she can purchase a three-day permit. This business model aims to serve more commuters and increase the occupancy in the underutilized lot after 3:00 p.m.

5.2.5.Zoning in parking garage

The University of Texas at Dallas (UT Dallas) has three parking garages with five levels each. The UPO divides the parking eligibilities based on the levels. Stalls at the base level are for payment by the hour. Upper levels are identified by four color zones. UT Dallas sells four different colors of permits with four different prices. Each permit holder should park the areas defined with the color indicated on the permit. Permit prices at the higher levels are cheaper than that at the lower levels. The concept is based on the fact that users who park at the higher levels need to drive to the floor and walk more to and from the vehicles. Detailed allowed permit divisions for the parking garages at UT Dallas is shared in [Table 9](#).

Table 9 - Parking garage zoning at The University of Texas at Dallas

Level	Permit Allowed	Permit Price (annual)
5	Green Permit	\$140
4	Gold Permit	\$250
3	Orange Permit	\$385
2	Purple Permit	\$595
1	Pay By Space	\$2 (per hour)

5.2.6. Zone identification

One important point in zoning is to inform the permit holders about the zones and the type of permits that are allowed to park, enforcement hours, fee schedule and so on. Of the 310 universities surveyed, 86% have campus maps that show the zones and detailed zone information in their UPO websites. The zone information is posted on signs at entrances of the parking lots. Three universities, Wright State University, University of North Carolina at Wilmington and Western Carolina University have different ways to inform users. Student stalls are identified with white markings, while employee stalls are identified with yellow markings.

5.3. Permit Sales and Pricing

In parking management, other than zoning, permit sales method and permit pricing are equally important. In fact, zoning, sales method, and pricing should be planned together. Permits are sold by the semester or annual basis and are made available before the semester starts. UPOs may assign priority to purchase permits among the student population by: (1) first-come-first-serve; (2) lottery; (3) by seniority according to credits earned. The parking office may also maintain a waiting list.

5.3.1. Occasional parking permits

Full-time students, faculty or staff tend to purchase annual or semester-based parking permits. Visitors have the opportunity to park in visitor lots or stalls. At University of Maryland, commuter students who use parking facilities occasionally may purchase “bundle pack permits”. Each bundle contains 10 one-day parking permits. Similarly, at Colorado State University at Fort Collins, if a commuter does not have an annual permit, he/she is eligible to purchase a pack of 10 day use hangtag permits.

5.3.2. Prioritization in permit sales

Zoning and prioritizations of users to zones have already been discussed in Section 5.2. This section focuses on the prioritization of permit sales. For example, University of California at Los Angeles offers a process that determines class standing (graduate or undergraduate status). The order to purchase parking permits starts with graduate students and then goes to eligible carpool users, followed by upperclassmen (seniors and juniors) and then underclassmen (sophomores and freshmen). University of Kansas has a similar procedure, in which the annual permits are available on different days to different types of students. Graduate students can purchase permit one week

before the seniors are able to do so. The one-week time lag is applied to juniors, and then sophomores. Oregon State University has a different approach in that the current permit holders can purchase parking permits 15 days earlier than the first time permit seekers.

5.3.3.Restrictions

In most universities, the number of parking stalls is lower than the potential demand. Prioritization in terms of zoning and sales sometimes are not sufficient to manage the demand. Therefore, some universities adopt policies to limit parking for certain students. For examples, University of California at San Diego, Stanford University, Emory University and University of Vermont do not allow first-year students to buy annual parking permits. University of Kentucky only sells permits to students who live at least one mile from campus and have at least 60 earned credits. Georgetown University offers a very limited amount of parking just for visitors and employees. Students are not allowed to park on campus. Likewise, New York University does not provide any stall to students and directs them to park in other facilities around the campus

5.3.4.No physical permit

ITS technologies allow UPOs and officers effective ways to verify parking permits and issue citations. By using License Plate Recognition (LPR) system, it may no longer be necessary for the parking office to issue physical parking permits (for examples stickers or hang-tags). The LPR system uses vehicle license plates as their parking permits. This system not only eliminates print out and distribution of the permits but also enable UPOs a way to control access to the parking lots. Enforcement vehicles having LPR technology can scan the license plates of vehicles parked and identify vehicles that do not have a proper permit. This technology can also be used to monitor lot occupancy. Examples of the universities that have taken advantage of the LPR technology in parking management are:

- California State University at Long Beach
- University of Missouri at Columbia
- University of North Carolina at Charlotte
- University of Kansas
- University of Rhode Island
- Stanford University
- University of North Dakota
- Murray State University

5.3.5.Day based permits

Some universities, for examples, Colorado State University, San Francisco State University, Portland State University, University of Wisconsin at Oshkosh, have a special option. If the commuter students travel to campus only two or three days a week (because of class schedule), they can purchase annual permits for (i) Monday, Wednesday and Friday; or (ii) Tuesday and Thursday. This allows parking office a better prediction of the daily demand.

5.3.6.Pricing strategies

Permit price is the most influential factor that affects students parking behavior. Several studies have examined the relationship between parking behavior and pricing. University campus parking was studied by Shoup (2017). In his book about the politics and economics of parking on campus, he concluded that nearly all the parking issues can be solved by appropriate pricing strategy which he believed was the only tool for planning. For example, California State University at Long Beach increased the daily parking fee by \$2 in 2016 while the semester permit rates remained unchanged. That change resulted in a 7% decrease in the number of daily permits sold while the sale of semester parking permits increased by 19% as compared to the previous year (CSULB 2017).

Universities have different strategies on setting permit prices. Some universities fix their permit prices a few years in advance. Colorado State University at Fort Collins and Texas A&M University declared their permit prices five years in advance. The University of Nevada at Reno adjusted the permit prices based on the previous year's occupancy information. At some universities, e.g., Florida Gulf Coast University, Boston College, parking is totally free. Some universities like Middle Tennessee State University, parking expenses are billed with tuition and other fees and all students have to pay a fee for parking. In this case, there is no extra fee for student parking. All the students just need to use their identification card to get the permit. In Massachusetts Institute of Technology, graduate students pay less for parking permits than the undergraduate students.

5.4.Access Control

UPOs want to ensure some of their facilities remain readily accessible for approved vehicles. Barrier with permit identification system at a parking lot's access point is an effective way to minimize illegal entries. Without using manual verification, the current technology, in addition to the LPR system as discussed above, is to use Radio Frequency Identification (RFID) tags and readers. This system enables automatic access into parking facilities with in-vehicle tags (for permitted vehicles) and readers at the gates. The technology also collects data for parking management office to monitor the real-time occupancy, individual vehicle or permit use.

5.5. Visitor Payment

In all universities, visitor parking is available in limited number of locations across campus with different parking and payment options. Visitors are the short term users and universities do not allow students or employees to park in visitor parking stalls. Some universities have only booths with guards asking visitors to pay while entering or leaving the campus. This section focuses on different ITS applications for visitor parking.

5.5.1.Smart device payment through apps

ITS can benefit visitors to spend less time searching and paying for parking. There are various smartphone applications in the market that help users to navigate and pay with their mobile devices. No coins, cash or physical credit card is needed for the payment. After users download the application, the user set up his account with a payment channel. When the user activates the

application, he/she then enters the location of the identification number of his/her parking stall, duration and then authorizes the payment. The user can later extend his/her stall use by making additional payment through the application. Since there are different smartphone applications adopted by universities, visitors may need to download different applications if they visit different campuses. Figure 11 lists the most common applications used for visitor parking at universities.







ParkMobile	paybyphone	Mobilemeter	Passport	Mobilenow	Whoosh
					

Figure 11 - Popular smartphone applications used for campus parking

5.5.2. Online visitor permits

Some universities are asking visitors to register their vehicles with the responsible offices while entering the campus. For example, in Central Michigan University, its Police Department is responsible for visitor and vehicle registrations. Visitors are required to obtain a permit from the Police Department by presenting their driving licenses and vehicle registrations. They should also inform where and how long they will be staying. The Police Department assigns parking privileges for specific lots and stalls depending on the purposes of the visits. Murray State University asks visitors to register their cars as well. The difference is in the registration process. It is done at an online parking portal. Approved permits are ready for the visitors to pick up at the parking office. This system still needs visitors a stop by an office to pick up the permits. This arrangement may be designed for safety and security of the campus, not just to manage visitor parking.

5.6. Data Collection and Guidance

In this section, data collection means obtaining information on parking lot occupancy. Collected data can be shared with the users or be used by the UPOs. The purpose is to count the number of parked cars inside a facility. Such statistics used to be collected manually. With the help of image processing technology, such as LPR, parked vehicles can be counted in real-time.

5.6.1. Manual survey informing users

Most of the universities are making manual counts to survey parking lots usage when necessary. UPOs keep the information for internal reporting or their decisions. Some universities, however, share the manual count information to the public. For example, University of North Carolina at Charlotte (UNC) counts its stall occupancy a few weeks into every semester to check that parking lot occupancy. UNC also uses this data for the planning of future parking facilities. At University of California at San Diego, parking and transportation services staff record and updates the

availability of parking lots four times per day during the first two weeks of the semester. The availability data is shared on their webpage.

5.6.2. Real-time occupancy information

With smartphone applications or in-vehicle navigation systems, drivers can follow the guided routes to university campuses, avoiding congestion spots along the way. However, the digital maps that come with such systems do not have information on parking on campus. Collecting real-time parking information and feeding them to a system that can be disseminated and shared is the solution that has been deployed by different UPOs. Some universities are already sharing their parking information in real-time. Florida Atlantic University, California State University at Sacramento, University of California at Riverside, University of North Georgia, Wayne State University and University of Oklahoma are just a few examples.

To go one step further, UPOs can install sensors on the surface or the ceiling of parking stalls to detect the presence of parked vehicles. Texas A&M University uses this technology in their parking garages to inform users about stall and lot occupancy using dynamic message signs (Figure 12). One other way to detect parked vehicles is to use image processing. At Auburn University, this system is used to count and share the real-time occupancy information in surface parking lots (Figure 13).

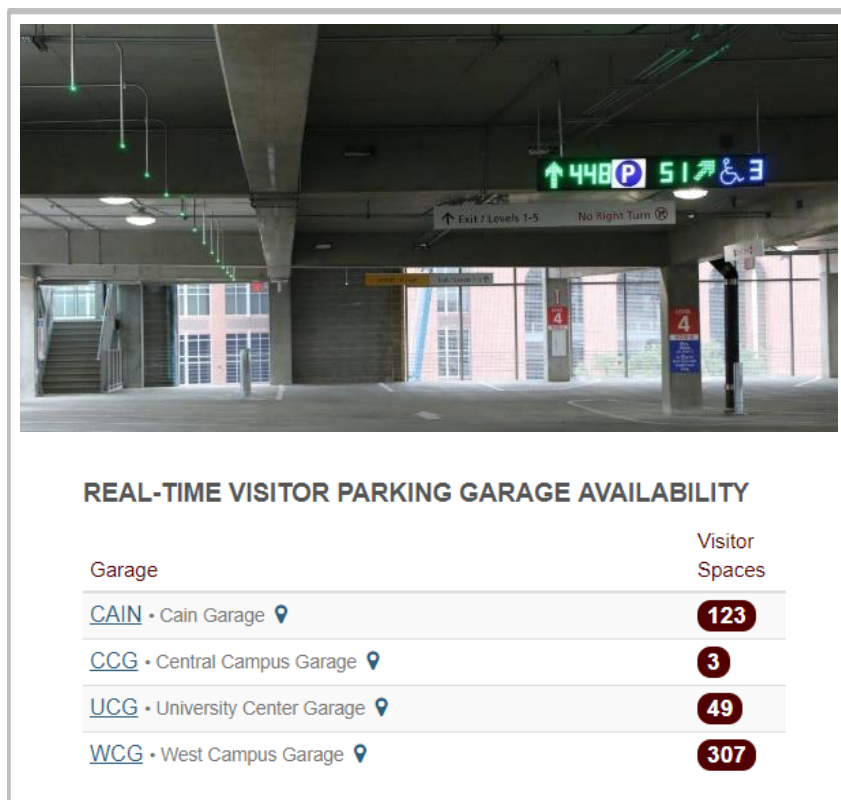


Figure 12 - Texas A&M University parking stall occupancy system
Source: Texas A&M University Transportation Services

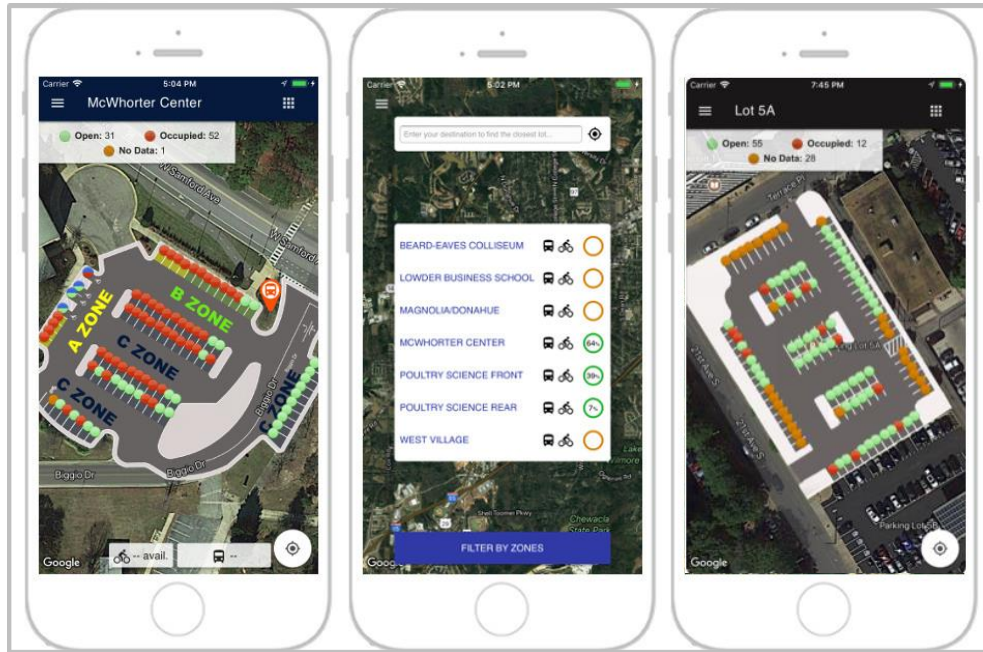


Figure 13 - Auburn University real-time stall information smartphone application
Source: Auburn University Parking Services

5.7. Enforcement

License Plate Recognition (LPR) allows vehicle license plates to be used as parking permits instead of physical permits, stickers or plastic hangtags. Some universities (Stanford University, Purdue University, University of Illinois, University of Arkansas, Ohio University) use this system in a limited way. They ask drivers to register with their license plate numbers with the UPOs and use the license plates as virtual permits. When a vehicle is parked on campus in a permit required lot, the license plate is captured by LPR cameras mounted onto a patrol-enforcement vehicle. When the camera scans a license plate, the number is automatically checked against the parking permit database. If a license plate is not associated with a valid permit, the system notifies the officer and the parked vehicle is subject to a citation.

5.8. Multi-modal Integration

Multi-Modal Integration (MMI) refers to efforts to connect various transportation modes (walking, cycling, automobile, public transit, etc.) to make the transfer between modes convenient. For university campus, MMI impacts both transportation within the campus (internal trips) as well as person-trips between the campus and the surrounding trip origins and destinations (external trips). In fact, MMI benefits the university by connecting the external trips with internal trips.

MMI is always implemented with parking policies that discourage parking near the center core of the campus. It offers a convenient “park-and-ride” service that brings commuters from their parked vehicles to the final destinations, i.e., “first mile” and “last mile”.

Among 310 universities explored in this research, majority of them (85%) have campus shuttle services to bring commuters who park at further locations (remote or outer zones) to the center core of the campus. The shuttle services usually have a fixed schedule but some delays are still expected. Only 39% of the universities that have campus shuttle services share real-time information of the vehicle locations. Very few universities (such as Florida State University, University of North Texas, Wayne State University, University of North Georgia) have their own smartphone applications to track the locations of shuttle buses, while other universities prefer to use the off-the-shelf system.

MMI integrating campus transportation with the city, county or regional transit systems (such as bus, light rail, mass transit), so that commuters may be found transit modes attractive enough than driving to campus. This potentially reduces the need for commuters to find parking on campus, helping to ease the parking congestion problem. UPOs of universities located in an urban setting can build partnerships with the city transit systems and offer differ a more direct, and faster transit service between the campus and major traffic generators.

6. PARKING, ENVIRONMENT AND COMMUNITY HEALTH

This chapter focuses on a framework to analyze the relationship between parking management, environment and community health in universities.

6.1. Metric of Community Health

Traditionally, a community is marked by a geographical boundary that forms a neighborhood, city, county, or state. In the context of community health, a community is “a group of people who have common characteristics”. In this sense, communities may be defined by geographical area, race, ethnicity, age, occupation, or a common interest ([McKenzie et al. 2011](#)). Community health refers to the physical, mental, and social health status of a defined group of people.

The U.S. Center for Disease Control and Prevention (CDC) recognizes that there is no widely accepted definition of community health. Nevertheless, CDC has developed a Community Health Assessment Tool ([CDC 2015](#)) part of it may be viewed as a metric for community health. CDC has two community health criteria ([County Health Statistics 2017a](#)): (1) length of life and quality of life, (2) The length of life criterion reflects the life expectancy. It has only one indicator: death before 75. The quality of life criterion has four indicators: low birth weight, poor or fair health, poor mental health days and poor physical health days. The values of the related indicators are available from county-level health statistics ([County Health Statistics, 2017b](#)).

[Cheu and Balal \(2018\)](#) recommended a community health metric consisted of three criteria: physical health, mental health, and social health. The indicators that were organized under the three criteria area:

- Physical health: low birth weight, poor or fair health, poor physical health days, adult obesity physical inactivity.
- Mental health: poor mental health days.
- Social health: alcohol-impaired driving death, injury death, public involvement.

Not all the above indicators are appropriate measures of the impacts of campus parking. For parking management on campus, the walking distance from parked stalls to the final destination (building) is the most obvious measure. For a university community, the total or average distance of all the travelers before and after the change in a transportation policy can be compared to evaluate the policy’s impact on community health. The indicator measures include those who switch mode from driving and park to taking transit, bicycle or other modes. Without detail information on the campus users’ trip origins (parked stalls) and destinations (classrooms, offices), it is impossible to make a good estimate of the walking distance. The problem is compounded by the lack of model or methodology to estimate when users would park their vehicles. Therefore, for the time and budget available for this project, the authors focused on establishing a framework to estimate the emission caused by a change in campus parking policy.

6.2. Modeling Framework

Air quality is one of the environment’s indicators. Air quality is related to community health. In order to have better air quality for a healthier community, a transportation system needs to reduce

its emissions. The indicators of air quality are CO, Pb, NO₂, O₃, PM_{2.5}, PM₁₀ and SO₂ (Cheu and Balal 2018). The U.S. Environmental Protection Agency (EPA) has developed a software named MOVES as the de facto standard tool to estimate vehicle emissions in a transportation network. MOVES is designed for emission estimation at the city or regional level. It depends on outputs of regional transportation planning models as its inputs. In regional transportation planning models, university campuses are usually modeled as one or at most a few Traffic Analysis Zones (TAZs). The road network and vehicle movements in a TAZ are not sufficiently detailed to capture any change in traffic pattern due to a change in parking policy. Very often, streets within the campus are not represented in the regional planning models. Therefore, an alternative modeling framework which includes using VISSIM microscopic traffic simulation followed by CMEM emission estimation has been proposed.

6.2.1.Simulation Tool

In the proposed modeling framework, VISSIM 5.4-12 (PTV 2013) is used to simulate the campus road networks and detailed vehicle movements. VISSIM was originally developed at University of Karlsruhe, Germany, with commercial distribution beginning in 1993 by PTV Transworld AG. PTV continues to distribute and maintain VISSIM today. VISSIM is a microscopic, time-stepping simulation model developed to analyze the roadways and public transportation operations. VISSIM can model multiple types of vehicles operating in roadway networks as well as other modes such as bicycle, and bus, which always appear in campuses. VISSIM can analyze traffic and transit operations under a variety of policy constraints, making it a useful evaluation tool to simulate traffic operations in campus road network and parking. Many versions of VISSIM have been developed over the years. The current version is VISSIM 10. In the proposed modeling framework, version 5.4-12 is recommended because it is fully compatible with CMEM.

6.2.2.Comprehensive Modal Emissions Model

CMEM is the acronym of Comprehensive Modal Emissions Model. It is developed by the Center for Environmental Research and Technology (CERT) at the University of California at Riverside along with researchers at the University of Michigan and Lawrence Berkeley National Laboratory, from a four-year research project funded by the National Cooperative Highway Research Program (NCHRP) Project 25-11 (Scora & Barth 2006).

CMEM has been developed as a microscopic emissions estimation model that calculates second-by-second fuel consumption and tailpipe emissions from individual vehicles. CMEM emission calculation process takes into consideration vehicle type, engine, emission technology, and level of deterioration. A critical input of CMEM is the speed of vehicles at one second intervals which VISSIM can provide, but not regional transportation planning models.

CMEM is a public domain software. The latest version of CMEM is Version 3.0. This version includes the latest 28 light-duty vehicle categories and 3 heavy-duty vehicle technology categories (Scora & Barth 2006). It is claimed to be the most detailed and best tested model for estimating vehicle exhaust emissions at different speeds and accelerations (Dowling et al. 2005). More information on the applications of CMEM can be found at (Barth et al. 1996; Barth et al. 1997; Barth et al. 1999; Barth et al. 2004).

6.3. Modeling Procedure

VISSIM and CMEM have been reviewed in the previous sections. This section describes how VISSIM and CMEM models work together to perform the desired tasks. The role of VISSIM is to simulate traffic operations in a campus' road network. The main outputs of VISSIM, in the context of this research, are network level transportation performance measures that describe the traffic conditions. Examples of such measures are total network travel time, total network delay, vehicle-miles traveled. These are the indicators for transportation in the metric described by [Balal and Cheu \(2018\)](#). In addition, VISSIM can also produce output that enables analysts to estimate total walking distance (equivalent to vehicle-miles traveled but for the walking mode) on selected links. However, VISSIM is unable to produce individual vehicle's emission at second-by-second level. To study the vehicle emission due to circulation on campus roads, vehicle speeds and accelerations at one second intervals are important. Therefore, vehicle trajectory data are generated by VISSIM and fed into CMEM for the later to make second-by-second emission estimation. In summary, the proposed VISSIM-CMEM framework allows analysts to evaluate the performance of a university campus transportation systems via the following measures:

- Transportation: total network travel time (vehicle-hours), total network delay (vehicle-hours), vehicle-miles traveled (vehicle-miles);
- Environment: CO₂ and other compounds mandated by the National Ambient Air Quality Standard (NAAQS);
- Community health: total walking distance (person-miles).

The above indicators are not exhaustive. For example, total cycling distance (person-miles) may be added as the second measure of community health. In addition, each indicator may be calculated for different trip types, for examples, for trips that are originated from or headed towards parking lots ("university trips"), and pass through traffic, respectively.

VISSIM is unable to simulate realistically the internal operations of a big parking lot. The simulations vehicle movements on campus roads in VISSIM is straightforward. The analyst simply needs to code the simulation model in the usual way. This includes defining the links and connectors, intersection controls, decision points and vehicle paths, vehicle compositions, Origin-Destination (O-D) matrices, evaluation files, and so on. Because of the need to compute the separate performance indicators for the "university trips" and pass through traffic, respectively, it is recommended to identify these two types of trips by the O-D zones and differentiate these two type of trips by different vehicle class.

VISSIM is to produce individual vehicle's dynamic data (speed, acceleration, grade, static load) at one-second intervals to feed into CMEM. For VISSIM to write an output file that has the necessary data for all the simulated vehicles (in the entire data collection period during a run), the following setting must be made.

From the VISSIM main menu, selects the "Evaluation" tab. A window likes the one in [Figure 14](#) will be displayed. In the "Vehicles" menu, select "Vehicle record" and "Configuration".

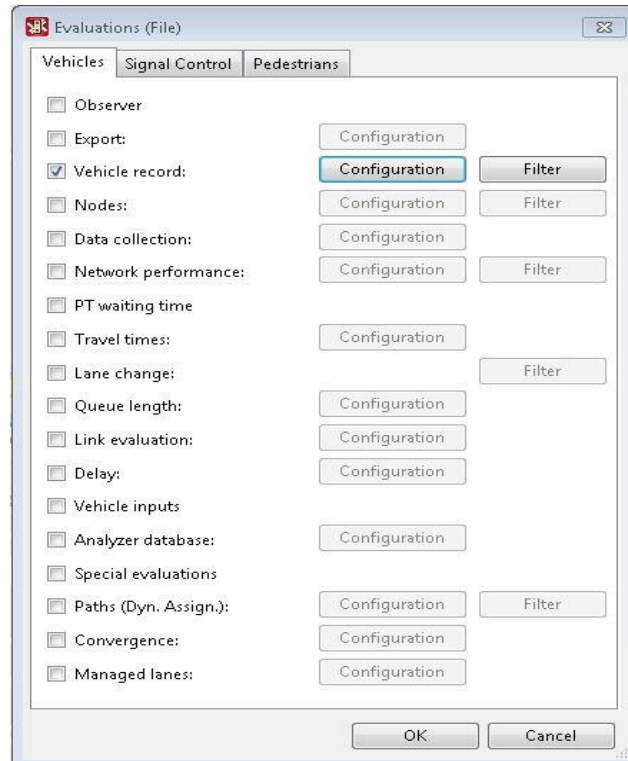


Figure 14 - VISSIM evaluation tab

In the next pop-up window (Figure 15), select the two parameters (speed [mph], acceleration). This is to tell VISSIM to write the values of the selected parameters, for every vehicle at every second, to a file named “esi.fzk”.

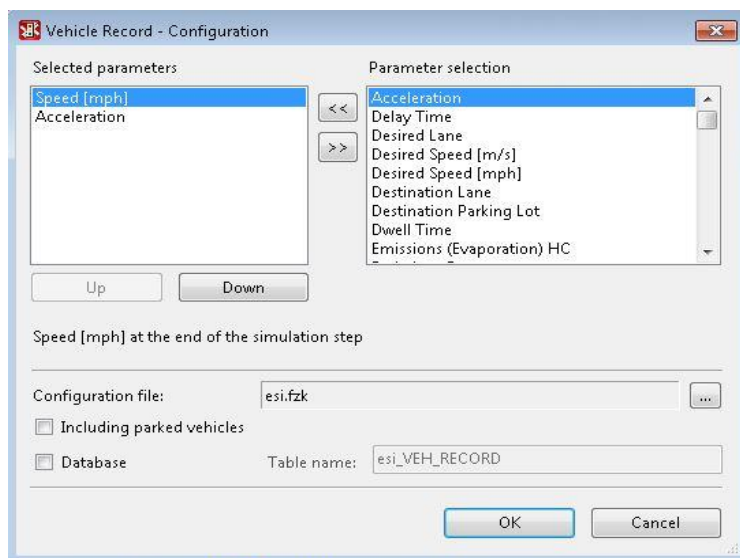
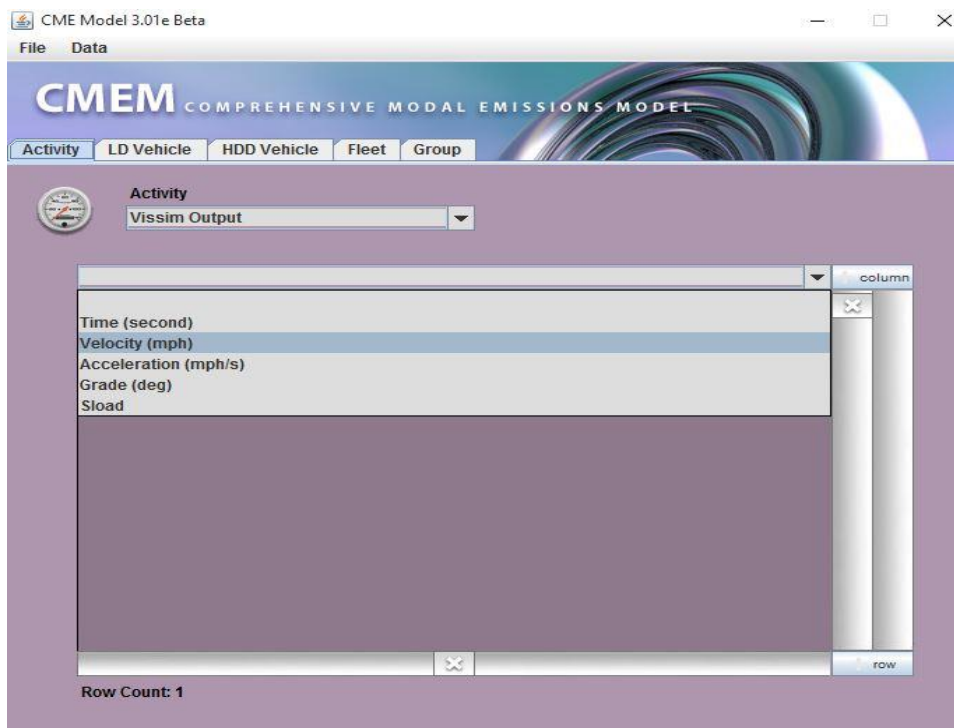


Figure 15 - VISSIM vehicle record - configuration

VISSIM simulation will produce an “esi.fzk” binary file at the end of a run. This file must be converted into a text file, with data arranged in four columns, one for each parameter. These data were imported into CMEM via setting that can be observed in the following screenshot. First, in CMEM’s “Activity” input window, select “Vissim Output”, followed by the compounds to be analyzed (see [Figure 16](#)).



[Figure 16 - CMEM activity tab](#)

At the completion of this step, CMEM will generate columns that correspond to the parameters selected. For each column or parameter, pull down the column header to select the column number in the import data file (reformatted from “esi.fzk”). Then, run the CMEM to estimate the quantity of the pollution causing compound. A sample screenshot of the outputs is shown in [Figure 17](#).

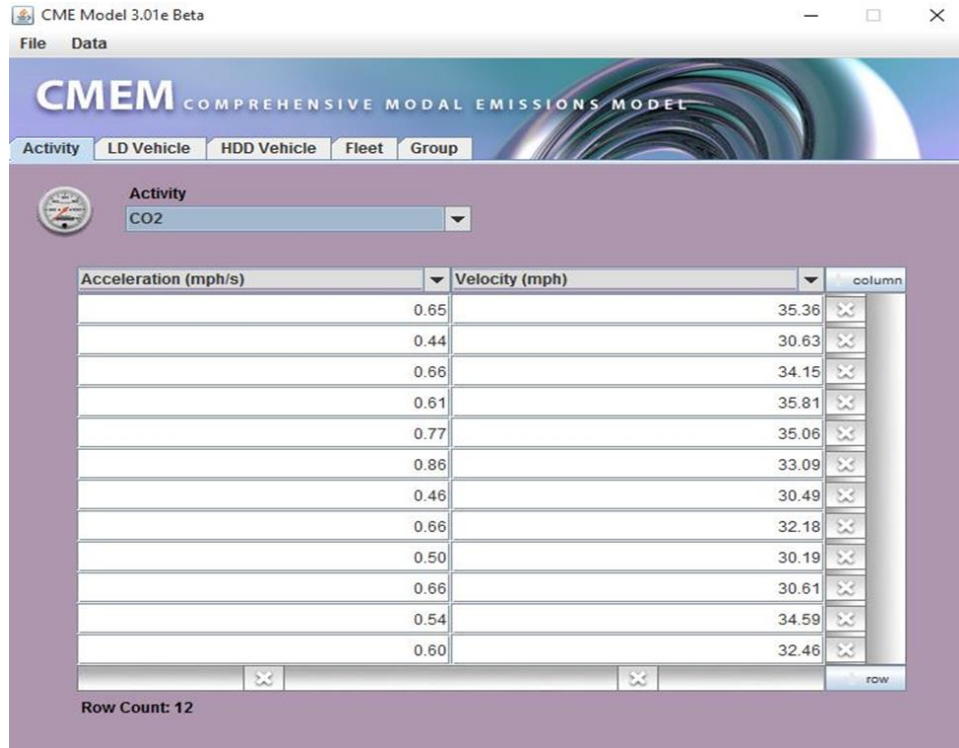


Figure 17 - CMEM CO₂ output

6.4.Demonstration

The university chosen for this demonstration was UTEP. The purpose of the case study was to demonstrate the working mechanism of the VISSIM-CMEM framework. The case study does not involve any experiment on the change in parking policy. The hypothetical purpose was to estimate the CO₂ emission caused by all the commuting vehicles coming to the campus between 8:00 a.m. and 9:00 a.m. on a weekday. The simulation did not make a distinction between faculty, staff, and students who were driving to campus. In fact, the vehicles driven by students may be distinguished by their destination (student) parking lots. To keep the demonstration simple, this VISSIM model assumed 100% single-occupancy vehicles, 0% truck and did not have campus shuttle bus.

A map of the UTEP campus and the surrounding area is shown in Figure 18 below. The UTEP campus is surrounded by I-10 Freeway in the west, Sun Bowl Dr. in the north, Mesa St. and Oregon St. in the east, and Schuster Ave. in the south.

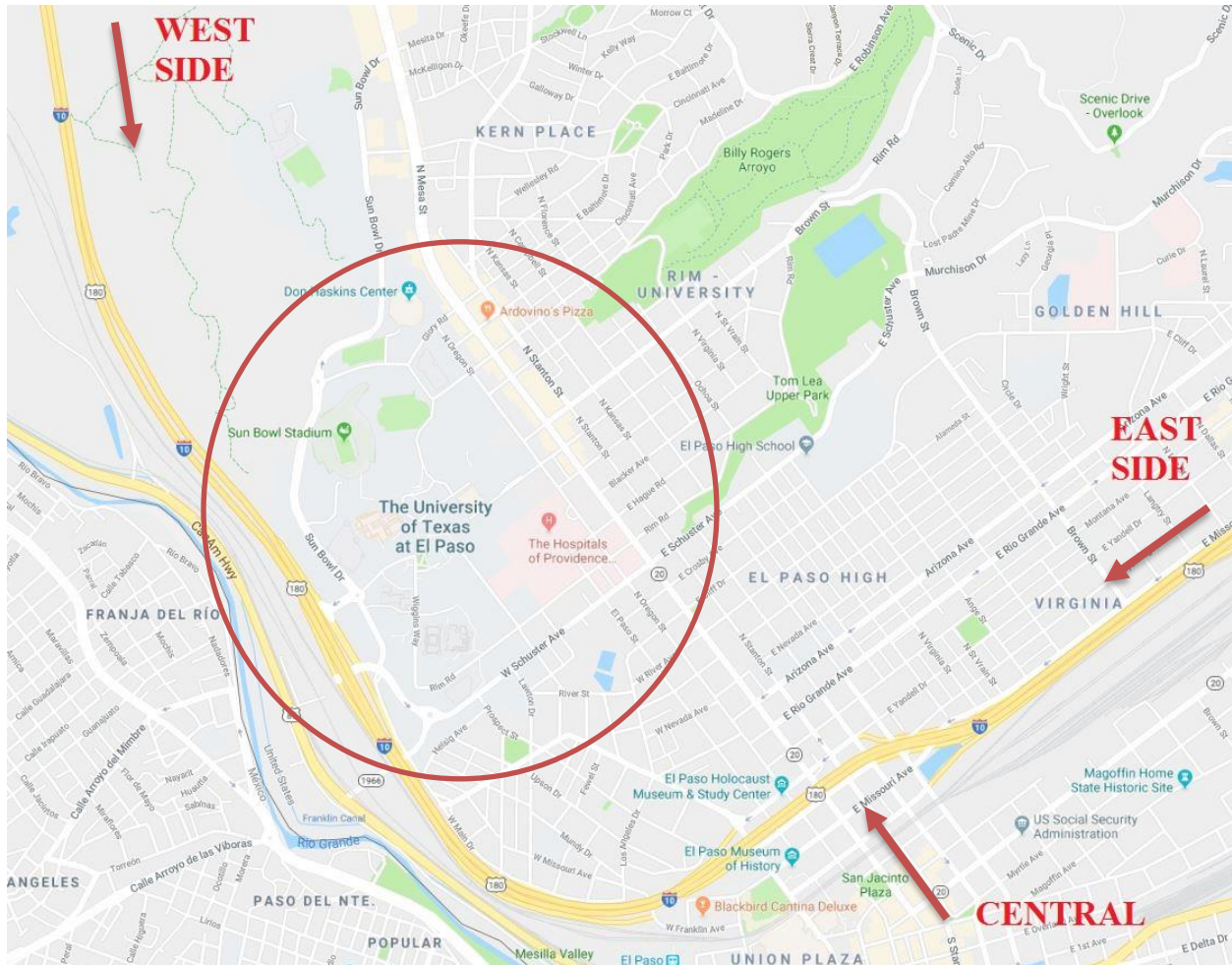


Figure 18 - Street map of The University of Texas at El Paso campus

The geometry and traffic schematic of the street network was coded in VISSIM based on information obtained from satellite images, verified by field observations. Traffic signal timing plans and intersection volume count data were provided by the City of El Paso. The whole coded network has 10,238 one-directional links and connectors which included 800 entry and exit links. These links and connectors have a total of 20 lane-miles off roadway facility. Figure 19 shows the screenshot of VISSIM with the coded links and connectors.

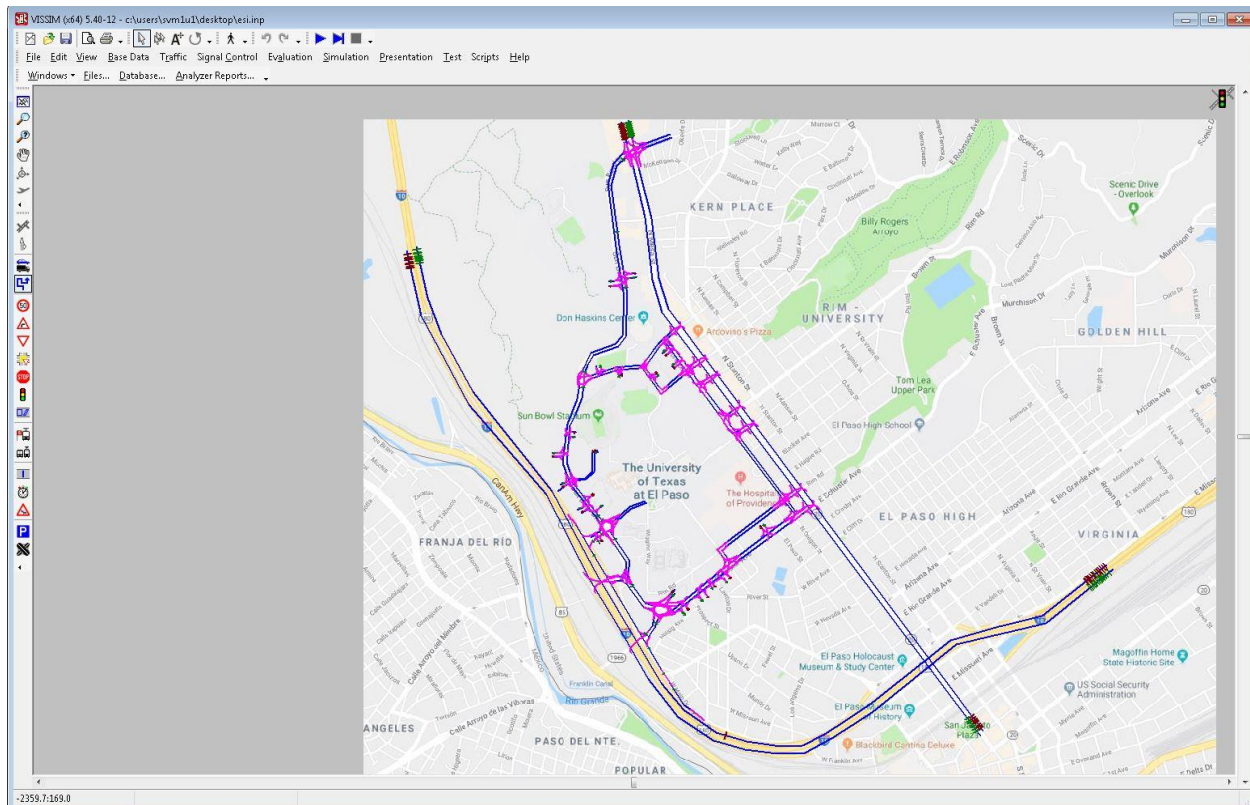


Figure 19 - Screenshot of VISSIM with the completed network

Figure 20 shows the locations of the parking zones on UTEP campus. Each parking lot is coded as an exit link in VISSIM. Within the simulated hour, the number of vehicles attracted to each parking lot was set to be the same as the number of stalls in the lot. The vehicle paths were constructed by identifying the shortest paths between the parking lots to the nearest points of approaches to the campus entrances. In the morning peak hour, vehicles approaching from the west side of the city enter the campus via (i) I-10 eastbound exit at Schuster Ave.; (ii) Sun Bowl Dr.; and (iii) Oregon St. turning right at University Ave. and Schuster Ave., while vehicles approaching from the east side of the city enter the campus via (i) I-10 exit at Schuster Ave.; (ii) Mesa St. turning left at Schuster Ave. or University Dr. Commuting vehicles coming from different origins in the city were assumed to follow these major approaches to the campus and proceeded to the parking lots. From the El Paso's Metropolitan Transportation (MTP) Planning Model (2016 Version), there were 21,215 veh/day from the west side (I-10 Freeway and Mesa St. combined), 8,940 veh/day from eastside and 1,625 veh/day from the center. Using the hourly factors provided by El Paso Metropolitan Planning Organization, these daily projected volumes were scaled to hourly volume between 8:00 a.m. to 9:00 a.m. It was found that the total parking capacity of UTEP campus was approximately 20% of all the traffic that entered the boundary points of the network. Therefore, 20% of the vehicles that entered the network followed the defined paths to the various UTEP parking lots. The remaining 80% formed the pass through (background) traffic along I-10 Freeway, Sun Bowl Dr., Mesa St., Oregon St., and Schuster Ave.

After the VISSIM model had been completed, the steps as described in Section 6.3 were followed. The VISSIM simulation was executed. The “esi.fzk” output file was set to the two essential columns: the individual vehicle’s speed, acceleration, for input into CMEM. In this case, the CMEM simply used the default grades of 0% and static loads. The VISSIM-CMEM estimated that on average, the CO₂ emission was 9.22 g/vehicle-mile, for vehicles that used the links on UTEP campus from 8:00 a.m. to 9:00 a.m. This was equivalent to 248,707 kg during the simulated hour. Other environmental indicators may be estimated in the same way.

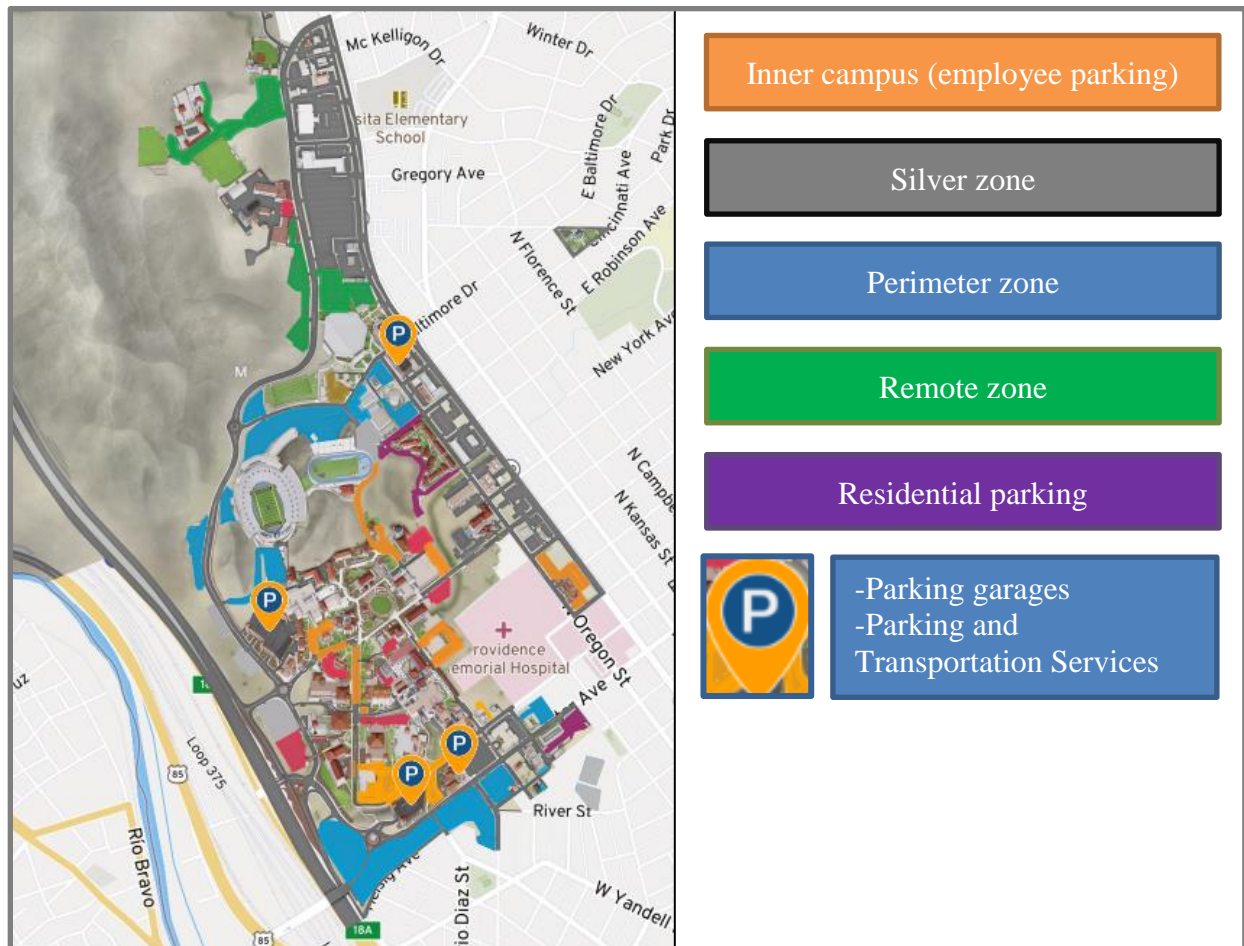


Figure 20 - Parking zones at The University of Texas at El Paso

7. CONCLUSIONS

This research has started with the objectives: (1) to understand the parking demand and management strategies at four different university campuses; (2) to identify innovative solutions to manage parking demand and supply on university campuses; and (3) to propose a framework to analyze the relationship between parking on a university campus with the environment and community health.

This report first reviewed the literature to explain the important parking terms and the unique characteristics of university campus parking. Parking demand, supply, and their interaction were explored with the studies done so far. Universities have different parking alternatives that attract different type of users (faculty, staff, student, and visitor) which makes the analysis of demand-supply interaction more complex. When the cost of parking and permit prices were compared, every new stall construction is an extra burden for the UPOs. Increasing university enrollment and heavy class schedules cause higher parking demands; that leads to parkers spend more time than previous academic years searching for empty stalls. One way to reduce the demand for parking is to encourage the university community to use transit, bicycle, walk, carpool and sustainable modes of transportation. All these characteristics of the university campus create spatial and temporal parking congestion problems, so are their solutions.

This report reviewed the parking demand and supply management strategies at four selected universities: Cornell University (Cornell), The University of Texas at El Paso (UTEP), University of California at Davis (UCD) and University of South Florida (USF). General information from universities including, demographics, statistics, climate information and some other possible factors that may affect parking demand were explored. Then, a comprehensive comparison was made between the four universities. It was observed that Cornell University is located in a rural area with nearly half of the students are living on campus. On the other hand, Cornell sets the highest permit price to manage the lowest student/stall ratio. UTEP, which is an urban setting public university, is struggling with insufficient capacity to handle the huge parking demand. UCD is a suburban public university that has the largest campus and highest headcount for the staff compare to others. UCD main focus in campus parking demand management is providing alternative means of transportation. Multimodal integration programs encourage commuters to pick alternative modes. USF has the highest number of student enrollment. USF provides free campus shuttle and collaborates with county transit to encourage commuters not to drive to campus.

After comparing the four universities' campus characteristics, parking, sustainable transportation options, and ITS applications in parking, this report surveyed innovative parking management practices in more than 300 universities that have student population of over 10,000. This report focuses mainly on the innovative applications of zoning, permit sales, pricing, access control, visitor payment, data collection, guidance, enforcement, and multimodal integration. Examples in universities throughout the nation were cited. These innovative solutions are important recommendations to improve parking management at the four universities. The solutions may be expanded to all the other universities nationwide.

This report also proposes a framework to analyze the relationship between parking management, and its impact on environment and community health. The goal is to evaluate the impacts of parking aimed or generated movements within the campus. The framework is based on the microscopic traffic simulation using VISSIM, coupled with the CMEM emission estimation model. A case study was performed, using the UTEP campus as an example, to illustrate the application of the proposed framework. The VISSIM-CMEM estimated that on average, the CO₂ emission was 9.22 g/vehicle-mile, for vehicles that used the links on UTEP campus from 8:00 a.m. to 9:00 a.m. This is equivalent to 248,707 kg during the simulated hour.

8. REFERENCES

- American Automobile Association. American Driving Survey, 2017, <https://newsroom.aaa.com/tag/american-driving-survey/> Accessed Sept. 18, 2018
- Apple Store, App Store Preview, “MyUSF Mobile” <https://itunes.apple.com/us/app/myusf-mobile/id373566943?mt=8> Accessed Sept. 18, 2018.
- Auburn University, Parking Services. “War Eagle Parking App” http://ocm.auburn.edu/newsroom/news_articles/2018/02/war-eagle-parking-app-helps-users-snap-a-spot.php Accessed Sept. 18, 2018.
- Barth, M., Scora, G., & Younglove, T. (2004). Modal emissions model for heavy-duty diesel vehicles. *Transportation Research Record: Journal of the Transportation Research Board*, (1880), 10-20.
- Barth, M., F. An, T. Younglove, C. Levine, G. Scora, M. Ross, and T. Wenzel. “The development of a comprehensive modal emissions model. (Draft) *Final report to the National Cooperative Highway Research Program*, November, 1999, 255 p.
- Barth, M., T. Younglove, T. Wenzel, G. Scora, F. An, M. Ross, and J. Norbeck, “Analysis of Modal Emissions from a Diverse In Use Vehicle Fleet,” *Transportation Research Record 1587, TRB, National Research Council, Washington, D. C.*, 1997, pp. 73-84.
- California State University at Long Beach Parking and Transportation Services. “Annual Report 2016-2017.”, <http://www.csulb.edu/sites/default/files/u26246/parking-annual-report-fy16-17.pdf> Accessed Sept. 18, 2018
- Center for Disease Control and Prevention (CDC). (2015, January 13). Community Health Status Indicators (CHSI 2015). <https://wwwn.cdc.gov/CommunityHealth/info/AboutData> Accessed Sept. 18, 2018.
- Chaniotakis, E., & Pel, A. J. (2015). Drivers’ parking location choice under uncertain parking availability and search times: A stated preference experiment. *Transportation Research Part A: Policy and Practice*, 82, 228-239.
- Cheu, R. L., & Balal, E. (2018). Development of a Comprehensive Metric to Evaluate the Impacts of Transportation-Environment on Community Health.
- College Data Online College Advisor. “College Profile.” <https://www.collegedata.com> Accessed Sept. 18, 2018.

Cornell University Division of Budget and Planning, Institutional Research and Planning. “Common Data Set Fall 2017.”, http://irp.dpb.cornell.edu/wp-content/uploads/2018/05/CDS_2017-2018-v5.pdf Accessed Sept. 18, 2018.

Cornell University Facilities and Campus Services. “Parking and Transportation.” <https://fcs.cornell.edu/content/parking-0> Accessed Sept. 18, 2018.

County Health Statistics Site. (2017). County Health Rankings & Roadmaps. <http://www.countyhealthrankings.org/our-approach> Accessed Sept. 18, 2018.

County Health Statistics Site. (2017). National Statistics Reference Table. http://www.countyhealthrankings.org/sites/default/files/resources/2017_NationalStatisticsReferenceTable.pdf Accessed Sept. 18, 2018.

Dowling, R. G. (2005). Predicting air quality effects of traffic-flow improvements: final report and user's guide (Vol. 535). *Transportation Research Board*.

Easy Park USA, Parking Solutions. “How it works?” <https://www.easyparkusa.com/how> Accessed Sept. 18, 2018.

FHWA Office of Operations. “Travel Demand Management.” http://www.ops.fhwa.dot.gov/aboutus/one_pagers/demand_mgmt.htm Accessed Sept. 18, 2018

General Services Administration. “Per Diem Rates.” <https://www.gsa.gov/travel/plan-book/per-diem-rates> Accessed Sept. 18, 2018.

George Mason University. “Parking and Transportation Overview.” <http://transportation.gmu.edu/wp-content/uploads/PT-Budget-and-Program-Overview-Aug-2015-081015-final.pdf> Accessed Sept 18, 2018

Gudz, E. M., Heckathorn, D., & Thigpen, C. G. (2016). Results of the 2015-16 Campus Travel Survey. Davis, CA.

Guo, L., Huang, S., & Sadek, A. W. (2013). A novel agent-based transportation model of a university campus with application to quantifying the environmental cost of parking search. *Transportation Research Part A: Policy and Practice*, 50, 86-104.

Infrastructure Partnership Australia. “Integrating Australia’s Transport Systems: A Strategy for an Efficient Transport Future.” <https://www.aph.gov.au/DocumentStore.ashx?id=e660c6b5-defe-4d16-a07d-bd622244b534&subId=32630> Accessed Sept. 18, 2018.

International Parking Institute (IPI). “Accredited Parking Organization (APO) Program.” <https://www.parking.org/professional-development/accredited-parking-organization-program/> Accessed Sept. 18, 2018.

International Parking Institute, (2015). “2015 Emerging Trends in Parking, Report on a Survey Conducted by the International Parking Institute.” <http://www.parking.org/wp-content/uploads/2016/02/TPP-2015-09-2015-Emerging-Trends-in-Parking.pdf>. Accessed Sept. 18, 2018.

Isler, E., Hoel, L., & Fontaine, M. (2005). Innovative Parking Management Strategies for Universities: Accommodating Multiple Objectives in a Constrained Environment. *Annual Meetings of the Transportation Research Board*, Washington, DC.

ITE Technical Council Committee. (2005). *Parking Generation*. USA

Kaplan, D. H. (2015). Transportation sustainability on a university campus. *International Journal of Sustainability in Higher Education*, 16(2), 173-186

Kenney, D. R. (2004). How to solve campus parking problems without adding more parking. *The Chronicle of Higher Education*, 50(29), B22-B23.

Krueger, T. (2008). Transit systems in college and university communities (Vol. 78). *Transportation Research Board*.

Litman, T. (2018). Parking Management Strategies. *Parking Management Best Practices* (pp. 86-225). Routledge.

McKenzie, J., Pinger, R., & Kotecki, J. (2011). An introduction to community health. Jones & Bartlett Publishers.

McTish, P., Park, S., & Schwarz, L. (2016). Efforts in Transportation Sustainability: Case Study of Villanova University. *International Conference on Transportation and Development* (pp. 259-269).

Moradkhany, A., Yi, P., Shatnawi, I., & Xu, K. (2015). Minimizing Parking Search Time on Urban University Campuses Through Proactive Class Assignment. *Transportation Research Record: Journal of the Transportation Research Board*, (2537), 158-166.

New North Transportation Alliance and the USF Center for Urban Transportation Research (2015). “USF Tampa Campus Transportation 2014 Survey Results.” <https://www.newnorthalliance.com/wp-content/uploads/2010/01/2015-01-USF-Transportation-and-Parking-2014-results.pdf> Accessed Sept. 18, 2018.

Proulx, F., Cavagnolo, B., & Torres-Montoya, M. (2014). Impact of parking prices and transit fares on mode choice at the University of California, Berkeley. *Transportation Research Record: Journal of the Transportation Research Board*, (2469), 41-48.

- Riggs, W. (2014). Dealing with parking issues on an urban campus: The case of UC Berkeley. *Case Studies on Transport Policy*, 2(3), 168-176.
- Scora, G., & Barth, M. (2006). Comprehensive modal emissions model (CMEM), version 3.01. User guide. Centre for Environmental Research and Technology. University of California, Riverside, 1070
- Shoup, D. (2017). *The High Cost of Free Parking*: Updated Edition. Routledge.
- Shoup, D. C. (2006). Cruising for parking. *Transport Policy*, 13(6), 479-486.
- Sperling's Best Places. "Cost of Living." <https://www.bestplaces.net/cost-of-living/> Accessed October 5, 2018.
- Sultana, S. (2015). Factors associated with students' parking-pass purchase decisions: Evidence from an American University. *Transport Policy*, 44, 65-75.
- Teodorović, D., & Lučić, P. (2006). Intelligent parking systems. *European Journal of Operational Research*, 175(3), 1666-1681.
- Texas A&M University Transportation Services. "Budget Facts and Figures." <http://transport.tamu.edu/About/budget.aspx> Accessed Sept. 18, 2018.
- Texas Tech University, Transportation & Parking Services. "Where Your Dollar Goes." <https://www.depts.ttu.edu/parking/Resources/Transparency/WhereYourDollarGoes.php> Accessed Sept. 18, 2018
- The League of American Bicyclists. "Universities across the U.S. recognized as bicycle friendly." <https://bikeleague.org/university> Accessed Sept. 18, 2018.
- The Sustainability Tracking, Assessment and Rating System, 2018 Submission. "University of South Florida." <https://stars.aashe.org/institutions/university-of-south-florida-fl/report/2018-02-19/> Accessed Sept. 18, 2018.
- The University of Texas at El Paso. "About UTEP." <https://www.utep.edu/about/about-utep.html> Accessed Sept. 18, 2018.
- The Weather Channel, Monthly Weather, <https://weather.com> Accessed Sept. 18, 2018.
- UC Davis. "Facts." <https://www.ucdavis.edu/about/facts> Accessed Sept. 18, 2018.

UC Davis Budget and Institutional Analysis, Campus Data. “Common Data Set.”
<http://budget.ucdavis.edu/data-reports/documents/common-data-set/cds20172018.pdf> Accessed Sept. 18, 2018.

UC Davis Transportation Services, Easy Park Personal Parking Meter,
<http://taps.ucdavis.edu/parking/permits/easypark> Accessed Sept. 18, 2018.

UC Davis Transportation Services. “Current permit types and rates.”
<http://taps.ucdavis.edu/parking/permits/rates> Accessed Sept. 18, 2018.

UCDS Transportation Services, Pay by App Pilot Program.
<https://transportation.ucsd.edu/parking/pay-by-app.html>. Accessed Sept. 18, 2018.

United States Census Bureau, American Fact Finder. “Community Facts.”
<https://factfinder.census.gov/faces/nav/jsf/pages/index.xhtml> Accessed Sept. 18, 2018.

University of Massachusetts Boston, Parking on Campus. “Parking Pro Forma Report.”
https://www.umb.edu/the_university/getting_here/parking Accessed Sept. 18, 2018.

University of South Florida System, Office of Decision Support, USF Tampa Campus. “CDS 2017-2018 Tampa.” <https://www.usf.edu/ods/documents/cds/cds2017-2018-tampa.pdf> Accessed Sept. 18, 2018.

University of South Florida, Facts and Statistics. “USF System Facts 2017-2018.”
<https://www.usf.edu/ods/documents/system-facts/usf-system-facts-2017-18.pdf> Accessed Sept. 18, 2018.

University of South Florida, Parking and Transportation Services. “Permit Rates Weekly Fee Schedule.” <https://www.usf.edu/administrative-services/parking/permits/permit-rates-weekly-fee-schedule.aspx> Accessed Sept. 18, 2018.

USF Administrative Services. “2015-2025 Campus Master Plan.”
<https://www.usf.edu/administrative-services/facilities/documents/planning/cdc/cdc-usftpa-master-plan.pdf> Accessed Sept. 18, 2018.

UT Dallas Shop Auxiliary Services. “Parking” <https://www.utdallas.edu/shop/parking/> Accessed Sept. 18, 2018.

UTEP Parking and Transportation VPBA. “Student Permits 2018-2019.”
<https://www.utep.edu/vpba/parking-and-transportation/parking/student-permits.html> Accessed Sept. 18, 2018.

Wolshon, B., & Pande, A. (2016). Traffic engineering handbook. John Wiley & Sons.

Zhang, X., Yang, H., & Huang, H. J. (2011). Improving travel efficiency by parking permits distribution and trading. *Transportation Research Part B: Methodological*, 45(7), 1018-1034