Trip and Parking Generation for Student-Oriented Housing Developments

by

Elizabeth Frances Hammer

A thesis submitted to the Graduate Faculty of
Auburn University
in partial fulfillment of the
requirements for the Degree of
Master of Science of Civil Engineering

Auburn, Alabama
May 5, 2013

Keywords: trip generation, student-oriented housing, parking generation, mode choice

Approved by

Rod E. Turochy, Chair, Associate Professor of Civil Engineering
Jeffrey J. LaMondia, Assistant Professor of Civil Engineering
Robert L. Vecellio, Associate Professor Emeritus of Civil Engineering

Abstract

While there are many different residential land uses in ITE's *Trip Generation Manual*, there is no land use category related to housing for college and university students. These housing developments are located off-campus, house mostly students, and are commonly found in college towns. The use of existing trip generation models for townhomes and apartments may lead to inaccurate predictions of trips due to students' travel behavior differences when compared to the general population. This study investigates the need for a separate land use consisting of student-oriented housing developments. Data were collected at twenty-six sites in three college towns: Auburn, Alabama, Clemson, South Carolina, and Tuscaloosa, Alabama, to determine if the trends differ from general apartment trip generation rates. A predictive model was developed using half of the collected data and checked using the other half of the data. This model was compared to *Trip Generation*'s Land Use 220, Apartments. Collected data supports the hypothesis that student-oriented housing does not follow the same trends as general apartments and a recommendation that the *Trip Generation* report should include a separate land use to account for these differences. Parking demand, mode choice, and the feasibility of a linear regression model with multiple independent variables were also studied. However, with the amount of available data, a meaningful model with multiple independent variables could not be developed. This research also suggests that the

parking demand is higher at student-oriented housing as opposed to general apartment housing developments.

Acknowledgments

This thesis would not have been possible without several key people. First of all, I would like to thank Dr. Rod Turochy for serving as my advisor for this project and Dr. Robert Vecellio and Dr. Jeffrey LaMondia for serving on my thesis committee. I would like to thank Brandy Ezelle, the traffic engineer for the city of Auburn, Alabama and Dr. Turochy for initially discussing the feasibility and need for this research project.

I would like to thank Paul and Marilyn Box for their contributions to the Paul and Marilyn Box Transportation Research Trust, through which my Graduate Research Assistantship was funded. In addition to funding this research, their contributions have enabled me and other students to attend conferences related to our studies. Speaking on behalf of all the transportation engineering graduate students at Auburn University, we are very appreciative of their financial gift to our program.

Numerous individuals contributed to the data collection for this project. I would like to thank Dr. Steven Jones at the University of Alabama and Dr. Wayne Sarasua at Clemson University for encouraging their ITE student chapters to volunteer their efforts. This project would not have been possible without these student chapter volunteers. My fellow transportation engineering graduate students at Auburn University were also instrumental in the data collection. I would like to thank Luana Ozelim, Derong Mai, Noah Morgan, Kristin Scurlock, and Clark Kennedy for their time and assistance with my data collection.

This research project would have never been attempted without the love and support of my parents, Roger and Theresa Hammer. Thank you for encouraging me to continue my education and pursue a graduate degree. Lastly, I would like to thank Darren Johnson for keeping me sane throughout this entire process and our four-legged friend, Zoe, for keeping us company in the office.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

ITE	Institute of Transportation Engineers
MAPE	Mean Absolute Percentage Error
OTISS	Online Traffic Impact Study Software
RMSE	Root Mean Square Error

Chapter One

Introduction

Transportation planners must accurately predict future traffic trends and impacts of a changing and developing community. Forecasting trips generated by new developments is one tool used by planners to identify the impacts on the existing transportation system and possible improvements needed to accommodate the additional traffic. Trip generation rates are derived from historical data that has been collected over time. Unfortunately, there are numerous land uses that have insufficient data. This study focuses on student-oriented housing developments, a land use that has no published trip generation rates.

A significant amount of effort occurs before a new development even breaks ground. Because new developments cause additional traffic, local jurisdictions typically require a traffic impact study to be completed. These studies analyze current conditions and predict the impact of the additional traffic generated by the new development. Growth factors can be applied to predict future traffic volumes. These traffic impact studies can help planners and engineers know if the roadway network needs to be modified in any way to accommodate the increased traffic volume. Possible modifications may include widening the roadway, adding or lengthening a turn-lane, or installing a traffic signal. Adding these modifications before completing a new development can help avoid problems in the future.

It is imperative that planners use accurate trip generation rates when completing traffic impact studies. Estimating too little traffic will result in a road network that is incapable of handling the new conditions. Overestimating trip generation could lead to the road network being overdesigned at great expense to the city or developer. Engineers frequently utilize a publication by the Institute of Transportation Engineers (ITE) to predict trip generation. The *Trip Generation Manual* contains data for numerous land uses. Individuals and organizations have submitted trip generation data to ITE since the 1960s. These data have been used to produce average trip rates and, sometimes, regression models, which can be used to predict trip generation rates for future developments. The plots are graphed as a function of vehicle trips versus an independent variable. The independent variables are typically the number of units for housing developments or square feet of floor area for a commercial development. Numerous land uses have multiple plots with different independent variables. Each plot provides the number of included studies, the average of the independent variable, the directional distribution, the average trip generation rate, the range of rates, the standard deviation among the rates, a fitted curve equation, and a coefficient of determination. There are separate plots for different times of the day or week. Typical plots include: weekday, Saturday, Sunday, weekday A.M. peak hour of the generator, weekday P.M. peak hour of the generator, weekday A.M. peak hour of adjacent street traffic, and weekday P.M. peak hour of adjacent street traffic. The peak hours of adjacent street traffic are assumed to be between 7:00 and 9:00 a.m. and 4:00 and 6:00 p.m.

The *Trip Generation Manual* contains models for predicting vehicle-trips for hundreds of very specific land uses ranging from residential to commercial to recreational. However, ITE does not publish a land use category for student-oriented housing developments. The United States has hundreds of college towns, most of which have off-campus housing available to students. These apartment complexes and townhome communities are typically not restricted to students, but students may occupy the majority of the dwelling units. A college town can be defined as a "city where a college or university and the culture it creates exert a dominant influence over the character of the community" (Gumprecht 2003).

Currently, to estimate trip generation for this type of housing, planners and engineers are forced to use existing residential land uses addressed in the *Trip Generation Manual*, such as Land Use 220: Apartments. Because Land Use 220 represents the general population as opposed to a specific group of people with different behavior and habits (i.e. college students), the predicted trip generation rates may not be accurate due to differences in demographic characteristics, automobile ownership, or transit accessibility. Vehicle ownership among students may be different than the general public and students' unique schedules may affect trip generation rates. The lack of available on-campus parking for students may encourage the use of other modes, such as public transit, walking, and bicycling.

1.1 Research Objectives

This thesis studies the number of trips generated by student-oriented housing developments with the intent of investigating more accurate methods of predicting generated vehicle-trips for student-oriented housing. This study analyzes the effectiveness of ITE's *Trip Generation Manual* and *Parking Generation* as well as identifies trends in students' transportation habits. The main objectives of this research project are:

1. Develop a trip generation model for student-oriented housing developments;
2. Compare this model to the model for ITE’s Land Use 220;
3. Quantify parking demand and compare to ITE’s *Parking Generation*;
4. Analyze the students’ mode choices;
5. Investigate the feasibility of predicting trip generation using other independent variables.

1.2 Scope

Trip generation and parking demand data were obtained from twenty-six sites from three college towns: Auburn, Alabama, Clemson, South Carolina and Tuscaloosa, Alabama. Half of the collected data was used to create a predictive model following the same format as the *Trip Generation Manual*. The other half of the data was used to analyze the accuracy of the predictive model as compared to ITE's Land Use 220. A similar process was performed for the study sites where parking demand was collected. In addition to bicyclist and pedestrian data, which was collected by volunteer data collectors, transit data was provided by Auburn University's Tiger Transit for the Auburn sites. A mode choice analysis was developed for these study sites. Additional variables were studied to determine if a linear regression model with multiple independent variables would be more effective.

1.3 Outline

Chapter two presents a literature review and analysis of the current state of available data. This chapter provides background information regarding the *Trip*

Generation Manual and *Parking Generation*. Findings from another study on the trip generation of student-oriented housing are provided. Despite a lack of existing research on student-oriented housing, another age-specific residential land use has garnered plenty of attention in the realm of transportation planning. Age-restricted housing developments, geared towards seniors, have been studied and findings support the existence of a separate land use category for these unique developments. The literature review also contains some critiques of the current methods using ITE's publications.

Chapter three explains the methodology behind this research project. The process of choosing cities and study sites is provided in this chapter. The chapter also contains the framework for the statistical analyses. Chapter four presents the results of the research project. In addition to trip generation rates and parking demand, the mode choice was analyzed and reported. Chapter five provides conclusions from the results of this research project. Suggestions and ideas for future research are given. The limitations of the research are provided along with ways to overcome them for future endeavors.

Chapter Two

Literature Review

Chapter two contains a review of scholarly literature relevant to this thesis. The chapter contains overviews of two ITE publications, the *Trip Generation Manual* and *Parking Generation*. The characteristics of college towns and student-oriented housing developments are summarized and a previous study regarding student housing is analyzed. The effects of another age-specific residential land use, age-restricted housing, has been previously studied and is summarized in this chapter. Age-restricted housing is typically designed for persons over fifty-five years of age. The chapter concludes with some of the concerns regarding current methods of transportation planning.

2.1 ITE's *Trip Generation Manual*

The Institute of Transportation Engineers publishes the *Trip Generation Manual*, an informational report that aids in estimating the number of vehicle trips generated by specific land uses. The most recent 9th Edition is based on more than 4,800 trip generation studies submitted to ITE by volunteers over the past few decades such as public agencies, consulting firms, universities, developers, and ITE Student Chapters (ITE 2012). None of the studies were conducted by ITE Headquarters. The report is meant for informational purposes only and does not suggest enforceable recommendations.

Data have been collected for various time periods, such as an average weekday, Saturdays, Sundays, the weekday morning and evening peak hours of the generator, the Saturday and Sunday peak hours of the generator, and the weekday morning and evening peak periods that occur during the traditional commuting peak hours of the adjacent street traffic. These peak periods are 7:00 to 9:00 A.M. and 4:00 to 6:00 P.M. The peak hour for the generator may or may not overlap with the peak hour of the adjacent street traffic, depending on the land use. Data are typically collected in suburban locations with little transit service or pedestrian amenities (ITE 2012). Developers must take into account the presence of public transit, ridesharing, or other travel demand management programs to accurately predict the number of vehicle trips that will be generated by their land use.

All of the reported data are for vehicle trip generation rates rather than person-trip generation rates. These rates represent the number of vehicles entering and exiting a development as opposed to the number of people traveling to and from the development. The submitted data were separated into entering and exiting traffic to establish a directional distribution.

Statistical analyses have been developed for all of the data in the *Trip Generation Manual*. The reported statistics include the average trip rate, which is based on a weighted average trip rate (total number of trips per total number of units) and the standard deviation, which measures how widely dispersed the trip rates for individual sites are around the average. Plots were generated with the vehicle-trips as the dependent variables and another variable as the independent variable. Independent variables can be the number of units, square footage of a development, or the number of employees. A regression analysis was also conducted for each plot. The software generates a regression curve, equation, and coefficient of determination (R^2). The R^2 value represents the proportion of variation in the data explained by the equation. Regression equations used in the *Trip Generation Manual* can either be linear, $T = aX + b$, or logarithmic, $Ln(T) = aLn(X) + b$. The regression equation is chosen based on which yields the highest R^2 value. Regression curves are only reported if the R^2 value is greater or equal to 0.5, the sample size is greater or equal to four, and the number of trips increases as the size of the independent variable increases.

2.2 Student-Oriented Housing

While college towns play an important role in shaping American culture, little research has been completed to quantify their effect on traffic patterns (Gumprecht 2003). These towns are unlike most other cities as they are youthful and diverse with a highly educated workforce. These smaller towns possess cultural opportunities otherwise only found in large cities (Gumprecht 2003).

Gumprecht studied the phenomenon of the American college town. While compiling his list of towns to study, he asked the following questions that can be answered quantitatively. Is the college the largest employer in town? What is the enrollment of the college, compared with the population of the city? What percentage of the labor force works in educational occupations? He narrowed his list to fifty-nine college towns and noticed some intriguing characteristics based on 2000 Census data. The median population age among the study towns was 25.9 years, about ten years younger than the median age in the United States. Adult residents in the towns were twice as likely as other adults in similar sized cities to possess a college degree and seven times more likely to hold a doctorate. Residents were half as likely as the United States population to work in manufacturing and four times as likely to work in education. The average median family income was $10,000 higher than families in similarly sized cities. These cities also had lower unemployment rates. Residents are relatively transient in college towns. College town residents are twice as likely as the United States population to have lived in a different state five years before. The majority of college town residents did not grow up in the area. Residents of college towns are more likely to rent and live in group housing. As of 2000, 70% of Americans lived in owner-occupied housing. Less than half of college town residents lived in owner-occupied housing in 2000 (Gumprecht 2003). There is a difference in a college town and city that is home to a college. Cities like Austin, Texas and Tempe, Arizona may not qualify as college towns. Austin contains the University of Texas but is also the state capital with plenty of activity outside of the university. Despite Tempe having the influence of Arizona State University, it is part of a major metropolitan area (Gumprecht 2003).

ITE's *Trip Generation Manual* does not have a land use specific to student-oriented housing. Student-oriented housing is similar to apartment and condominium developments due to the high density of residents and relatively low trip generations (SDSU 2010). Student-oriented housing developments experience lower trip generation rates than generic multi-family apartments or condominiums. This phenomenon can be attributed to many students not owning cars and the fact that many trips are close to the campus area and can be completed by bicycling, walking, or using public transit (SDSU 2010). There is very little published research regarding student-oriented housing developments and the vehicular trips generated by these developments.

Recent growth in new residential construction surrounding the University of Minnesota campus encouraged a study of the trip generation rates of newly constructed and occupied student-oriented apartment buildings in Minneapolis, Minnesota, a highly populated urban area, unlike Auburn (Spack 2012). Data were collected for six apartment buildings on Thursday March 29, 2012. The buildings ranged from forty-four to 253 units per building, including studios up to four-bedroom apartments, with an average of 118 units. The buildings contained forty to 135 parking stalls with an average of fifty-seven parking stalls. Therefore, the buildings had roughly one parking stall for every two units. With plenty of units housing multiple students, automobile ownership appears to be very low among students in this area.

Entering and exiting vehicular trips were recorded for the twenty-four hour period using a video recording system. Trip generation rates were provided in terms of trips per dwelling unit, trips per bedroom, and trips per parking stall. Weekday, weekday a.m. peak hour, and weekday p.m. peak hour rates were calculated. The a.m. and p.m. peak hours were the peak hour of adjacent street traffic. The study compares the collected data to Land Use 220 in ITE's *Trip Generation* report. The results suggest that student-housing generates approximately one-third the amount of traffic as generic apartments. The average rates for the collected data and the rates reported by ITE are shown in Table 2.2.1

Table 2.2.1: Average Trip Generation Rates per Number of Dwelling Units for the University of Minnesota Study

	Student Housing Apartments	Apartment from *Trip Generation, 8th Edition*
Weekday	2.82	6.65
Weekday A.M. Peak Hour (between 7-9 a.m.)	0.13	0.51
Weekday P.M. Peak Hour (between 4-6 p.m.)	0.24	0.62

Source: Spack 2012

Nine plots were developed from the collected data, including weekday, weekday a.m. peak hour, and weekday p.m. peak hour for the three previously mentioned types of trip generation rates: trips per dwelling unit, trips per bedroom, and trips per parking stall. For the trips per dwelling unit plots, the weekday and weekday a.m. peak hour fitted equations resulted in coefficients of determination, R^2, greater than 0.8. The R^2 value for the weekday p.m. peak period was less than 0.5. The fitted equations developed for trips per number of bedrooms had less validity, with R^2 values less than 0.55. The fitted equations for trips per parking stall resulted with the highest average R^2 value. The weekday and weekday a.m. peak hour plots each had an R^2 value greater than 0.9 (Spack 2012). Keeping in accordance with ITE's guidelines, full traffic impact studies need to be completed anytime more than 100 trips would be generated during the peak hour. The collected data suggests that a student-housing apartment complex would need to have at least 416 dwelling units to require a full traffic impact study (Spack 2012). The location of the collected data hinders its applicability to this study. City location and the type of study sites can cause significant variations in collected data. A large city produces different travel patterns than a traditional college town. While a college town typically has transit services, parking at residential and commercial developments is rarely limited. Travel patterns of students in large cities may be more affected by their urban setting rather than their age-specific habits.

2.3 Age-Restricted Housing Developments

The transportation planning community has accepted that age has a substantial effect on one's travel behavior. For example, several studies have been completed regarding the travel patterns of those residing in senior housing. Age-restricted housing developments are typically designed for persons fifty-five and older. These developments contain attached or detached houses for independent living but may include lawn and maintenance services along with social activities for the residents. Many of the residents are retired, but plenty are still employed. Age-restricted housing developments are not the only developments geared towards seniors. In addition to detached and attached senior adult housing, the *Trip Generation Manual* also has land uses for congregate care facilities, assisted living facilities, and continuing care retirement communities. Congregate care facilities are independent living developments that provide amenities such as dining, transportation, housekeeping, social activities, and some medical services. Continuing care retirement facilities include a combination of all types of care and are intended to allow a resident to remain in the same facility despite their changing needs (ITE 2008).

Changes in legislation have allowed these communities to develop more rapidly. The Civil Rights Act of 1968, also known as the Fair Housing Act, limited age-restricted housing developments for years. This act prohibits discrimination in housing and was modified in 1988 to prohibit discrimination based on familial status, including the presence of children. The Housing for Older Persons Act of 1995 reduced the requirements for senior housing to have “significant facilities and services designed for the elderly” and declared that communities aimed towards those over the age of fifty-five could exclude families with children (Flynn 2007).

There are several published studies indicating that retirement communities generate fewer vehicular trips than standard housing. Age-restricted housing developments appear to only generate about one-fourth of the vehicular trips expected from a single family detached housing development during the evening peak hour (Racca 2006). The Office of Highway Policy Information within the Federal Highway Administration publishes a National Household Travel Survey with the help of the United States Census Bureau. Formerly the Nationwide Personal Transportation Survey, it serves as the nation’s inventory of daily travel. Surveys are distributed and data are recorded regarding the purpose, mode of transportation, travel time, and the time of day and week of each trip. Data from past National Household Travel Surveys indicates that trips reduce with age, suggesting that not all seniors have similar behaviors nor maintain their behaviors throughout their entire retirement. Despite trips reducing with age, the number of miles traveled by those over sixty-five years of age has increased (AARP 2011).

The lifestyle of a person over fifty-five years old has several characteristics that cause different travel patterns. These people are less likely to be employed, as they are nearing retirement age. This results in fewer work trips, but free time may lead to more non-work trips that are not taken during the traditional peak periods. These people may have the flexibility to avoid the busiest times on the highways. The peak hours of trip generation for senior housing developments typically occur in the late-morning or early afternoon (Corcoran 1996). People over the age of fifty-five are less likely to have children living in their household, and are not likely to relocate to an age-restricted housing development until their children are out of the house. This reduces the need for children-related trips. Smaller households suggest fewer trips and trip generation data is typically recorded on the household or unit level and not the individual (Racca 2006).

There are several factors that influence the trip generation and parking demand at a senior living facility. In addition to the number of dwelling units or beds, the average age of the residents, the affluence of the community, the number of employees, and the existence of a shuttle system. The relationship between trip generation and parking demand is difficult to analyze as trip generation rates can differ greatly between housing developments. It is difficult to collect all necessary information on survey locations to fully realize the impact of the previously mentioned factors. Naturally, there is evidence that the number of trips generated and the parking demand diminish as the age of residents increases. Affluence suggests that residents are more likely to own an automobile and travel more frequently. Similar to other housing developments, the presence of a shuttle service reduces trips and parking demand as residents are given a convenient alternative to driving (Corcoran 1996).

Flynn and Boenau published a study regarding an age-restricted housing community in the northern Virginia suburbs. This study suggested that the *Trip Generation Manual* may be underestimating the actual number of trips generated by age-restricted housing communities, even using Land Use 251: Senior Adult Housing-Detached (Flynn and Boenau 2007). Since this article was published, ITE has accumulated significantly more data for this land use. Three other studies found similar results. Jeihani and Camilo studied four age-restricted housing communities in Maryland and found that their study sites produced approximately three times as many trips as the *Trip Generation Manual* predicted. However, their study sites still generated considerably fewer trips than the *Trip Generation Manual* would predict for standard detached housing (Jeihani and Camilo 2011). This indicates that despite some inconsistencies within the data, age-restricted housing needs to remain a separate land use from standard detached housing. The city of Evansville, Indiana (EUTSMPO 2001) and the Southern New Hampshire Planning Commission (SNHPC 2007) found similar results. Both concluded that the *Trip Generation Manual* underestimated vehicle-trips generated by the sites in their study area.

Baby boomers are very different than their parents. In addition to an older population, the seniors of the future are expected to be more active than those before them (AARP 2011). The *Trip Generation Manual* contains data dating back to the 1960s. Therefore, some data points for age-restricted housing may have been collected from communities with seniors very different from the seniors today.

2.4 ITE's *Parking Generation*

The Institute of Transportation Engineers (ITE) publishes a manual entitled *Parking Generation*. This manual helps users understand and estimate parking demand for many different land uses. The most recent edition, the 4th Edition, was published in 2010 and includes 107 land uses ranging from residential land uses, such as townhomes, to commercial land uses, such as shopping centers and banks (ITE 2010). Data collection is performed by volunteers and is not part of a financed research effort. *Parking*

Generation does not "provide authoritative findings, recommendations, or standards on parking demand" (McCourt 2004). The report is intended to be used as a tool to understand parking demand and users must be aware that all developments have unique characteristics that can affect their parking generation. The majority of the data in *Parking Generation* are from isolated single land use suburban sites with free parking. The type of area surrounding the land use, the availability of transit services, and the use of demand management strategies can affect parking generation. *Parking Generation* is not intended to be an authoritative standard, but provides the best available data that may be necessary to accurately determine parking need (ITE 2010).

The ability to accurately predict the amount of parking necessary for a land use can save developers money, minimize undue environmental impact, and reduce traffic congestion. Typical surface parking costs $1000 to $3000 per space. Structured or underground parking is used in more urban areas and comes at an even higher premium. Larger parking areas have a more severe impact on storm water runoff and water quality mitigation can be costly. Larger parking areas can also expose people to warmer areas. Providing too little parking can result in drivers traveling to adjacent neighborhoods and businesses and can cause an increase in vehicle miles traveled due to increased circulation (McCourt 2004).

2.5 Issues in Site Studies

Accuracy and the usability of data is an ongoing challenge for transportation engineers and urban planners. Estimates can often be reported as precise numbers which can lead to poor planning. Trip generation and parking demand data are commonly observed at suburban sites with ample parking and no public transit. These sites typically do not have pedestrian amenities or transportation demand management programs. This data can be useful for planning for similar suburban developments, but does not provide an accurate guide for urban development. The *Trip Generation Manual* mentions that most study locations are in suburban areas but does not report the cost of parking. Parking is free for 99% of vehicular trips in the United States, so it can be assumed that the majority of the sites offer free parking (McCourt 2004).

Plenty of the reported trip generation rates are based on fewer than five studies. The *Trip Generation Manual* reports an average trip generation rate for all plots, even those with extremely low coefficients of determination. Low coefficients of determination suggest that there is not a relationship between the independent and dependent variables, so an average trip generation rate is useless and inaccurate. Data is frequently reported to multiple decimal points, suggesting a high level of precision. Transportation planning would not be affected if these rates were rounded, but the precise numbers give a false sense of accuracy.

Similar to the trip generation data, many of the rates published in *Parking Generation* are based on only a few studies. The parking demand rates are typically measured at sites similar to the trip generation sites. These sites are located in suburban areas with sufficient parking and no public transit. If urban planners were to use these rates to set minimum parking requirements, people would drive everywhere and find free parking at their destinations.

Shoup of the University of California Transportation Center is extremely critical of the Institute of Transportation Engineers' publications. He states that "parking generation rates are hardly scientific, but the ITE's stand of authority relieves planners from the obligation to think for themselves" (Shoup 2002). Despite the report warning users to exercise extreme caution when utilizing data that is based on a small number of studies, many planners use the parking generation rates to set minimum parking requirements, which leads to an abundance of parking spaces. The average parking requirement for fast food restaurants in the United States is ten spaces per 1,000 square feet of floor space, which is almost identical to *Parking Generation*'s average parking generation rate of 9.95 vehicles per 1,000 square feet.

However, not everyone shares the same concern regarding overestimating parking demand and trip generation rates. Dr. Francis Navin of the University of British Columbia suggested using the 85th percentile rate as opposed to the average rate. He reasoned that using this rate reduced the risk the actual development generation being higher than predicted from fifty percent to fifteen percent (Navin 1995). This reduces the chance that the road system will not be able to handle the additional traffic generated by a new development. It also increases the chance that a road system will be overdesigned and incur unnecessary costs.

Shoup brings attention to the difference between "parking occupancy" and "parking demand". Parking occupancy is defined by transportation engineers as the number of parked cars. Economists define parking demand as the relationship between the price of parking and the number of parked cars. The actual number of parked cars is the quantity of parking demanded at a specific price. Therefore, the majority of the occupancies reported in *Parking Generation* can be defined as "the quantity of parking demanded at a zero price at the time of peak parking demand" (Shoup 2002).

ITE has made progress towards improving the quality of their data. Additional studies have been added over the years and a new policy for reporting data was implemented with the 5th Edition of *Trip Generation* in 1991. Best fit curves are only shown when three conditions are met: the coefficient of determination is greater than or equal to 0.25, the sample size is greater than or equal to four, and the number of trips increases as the size of the independent variable increases. The last of the three conditions is unscientific and could be misleading. In the case that the number of trips decreases as the size of the independent variable increases, an average trip generation rate would still be reported. The average trip generation rate would imply that vehicle trips increase as the independent variable increases. The lack of best fit curve could conceal the true relationship between the data. For the 6th Edition of *Trip Generation*, regression equations are only shown if the coefficient of determination is greater than or equal to 0.5, an R^2 value that suggests a tighter fit curve than the original threshold of 0.25. This edition only presented regression equations for 34% of the trip generation rates, meaning two-thirds of the rates fail to meet at least one of the criteria (Shoup 2002).

One concern about the accuracy of ITE's trip and parking generation rates is the age of some of the collected data. Some data are several decades old and are simply not relevant anymore. Travel patterns change over time and a development in the twenty-first century cannot be planned based on data from the 1970s (Shoup 2002). Regional bias also exists in the data. It is hard to predict what will happen in one area based on historical data from the other side of the county. Transoft Solutions is developing a solution. Transoft has recently released Online Traffic Impact Study Software (OTISS). OTISS begins to alleviate some worries about the irrelevancies of ITE's data. The software claims to house ITE's data and will also a user to filter out data based on age or location of the data (Transoft 2013).

2.6 Summary

This chapter explored the existing research related to student-oriented housing developments and their effect on trip generation and parking demand. There is little existing research regarding the trip generation of student-oriented housing. The one published study involves developments in a highly urban area with limited parking availability. This is significantly different than the phenomenon of a college town.

Age-restricted housing has been studied extensively and has been included in ITE's publications as its own land use. Studies indicate that age-restricted housing generates fewer trips, especially during the peak periods, than traditional residential housing. The research of age-restricted housing indicates that demographic characteristics influence travel behavior.

Chapter Three

Methodology

This chapter includes the theory and reasoning behind the selection of college towns and specific student-housing developments that would be used for data collection purposes. This chapter provides guidance regarding the necessary data to be collected. A statistical analysis was performed to compare the relationship of the observed vehicular-trips and number of dwelling units to the ITE *Trip Generation* report's Land Use 220 models. Land Use 220 represents general apartment dwelling units. Other characteristics, such as distance from campus and average rent, were used to perform a multiple-regression analysis to evaluate the feasibility of developing another model to predict vehicular-trips generated by student-oriented housing developments. Additionally, a study of the parking demand was completed and compared to ITE's *Parking Generation* report. Land Use 221, representing low to mid-rise apartments was used.

3.1: City Selection

Demographic data were collected for various college towns to assist with the selection of cities to be included in the study. Due to resource constraints, only colleges and universities in the southeastern United States were considered. Collected information included the distance from Auburn, Alabama, the number of undergraduate students and the total enrollment at the college or university, the number of students living on campus, the city or town population, and the county population. The city or town population includes the number of students who claimed the city as their residence in the 2010 Census. The existence of a civil engineering program at the college or university was also noted. A civil engineering program could provide additional resources for site selection and data collection.

The distance was collected to indicate the feasibility of an in-person visit to the college or university. Preference would be given to closer potential collection sites. The undergraduate enrollment, total enrollment, and city and county populations were collected and analyzed to provide demographic information of the area. The number of students living on campus was found on university webpages or through contact with the various university housing offices. The number of students living off campus was found as the difference in total enrollment and the number of students living on campus. The potential sites and the information mentioned previously are provided in Tables 3.1.1 and 3.1.2. Table 3.1.1 consists of collected characteristics, such as university enrollments, populations, and distances from Auburn, Alabama. Table 3.1.2 consists of measures derived from those presented in Table 3.1.1.

Table 3.1.1: Potential Data Collection Site Characteristics

Location	Distance from Auburn (miles)	Under-graduate Enrollment	Total Enrollment	On-Campus Population	City Population	County Population
Athens, GA	179	25947	33796	8000	115452	124714
Auburn, AL	0	20221	25078	4000	53380	140247
Clemson, SC	236	15459	19453	6500	13905	119224
Cookeville, TN	324	9920	11768	2250	30345	72321
Gainesville, FL	318	32064	50116	9400	124354	247336
Oxford, MS	296	14159	17085	5000	18916	47351
Starkville, MS	241	15543	19644	4000	23888	47671
Tuscaloosa, AL	160	26234	31747	8000	90468	194656

Table 3.1.2: Student Populations of Potential College Towns

Location	Off-Campus Population	Ratio of Students to Town Population	Ratio of Students to County Population	Ratio of Off-campus Students to Town Population	Ratio of Off-campus Students to County Population
Athens, GA	25796	0.293	0.146	0.223	0.111
Auburn, AL	21078	0.470	0.179	0.395	0.150
Clemson, SC	12953	1.399	0.163	0.932	0.109
Cookeville, TN	9518	0.388	0.163	0.314	0.132
Gainesville, FL	40716	0.403	0.203	0.327	0.165
Oxford, MS	12085	0.903	0.361	0.639	0.255
Starkville, MS	15644	0.822	0.412	0.655	0.328
Tuscaloosa, AL	23747	0.351	0.163	0.262	0.122

Once the preceding quantities were collected and analyzed, correspondence began with city traffic engineers and faculty advisors for the Institute of Transportation Engineers (ITE) student chapters at each candidate institution. City traffic engineers were questioned regarding unique characteristics of their city and whether similar studies had been completed in their area. ITE student chapters were contacted regarding the possibility of assistance with data collection. Due to resource constraints and logistics, preference was given to universities that could provide student volunteers for data collection efforts. Auburn, Alabama, Clemson, South Carolina, and Tuscaloosa, Alabama were eventually chosen as the sites for data collection. Primarily, these three cities were home to ITE student chapters and civil engineering departments that were willing to provide human resources and guidance for data collection. The proximity between the three sites allowed for trips to both Clemson and Tuscaloosa to meet with volunteers and observe the data collection sites.

3.2 Site Selection

The ITE student chapters at Clemson University and the University of Alabama were asked to select apartment complexes for data collection. The chapters were provided guidance regarding their selections. Suitable sites were apartment complexes with at least thirty dwelling units that housed mostly students. ITE student chapters were asked to find certain characteristics of each site, such as distance from campus, number of units, number of total bedrooms, availability of transit, transit time to campus, transit frequency, and average rent. Small apartment complexes with less than thirty units were not considered, as they might not be statistically relevant. Due to human resource constraints, preference was given to the sites with fewer entrances, as they required fewer volunteers for data collection.

3.3 Data Collection

The data were intended to be collected on weekdays during the peak hour of adjacent street traffic. All data collection occurred on Tuesdays, Wednesdays, and

Thursdays to represent typical weekdays. Data were collected from 7:00 a.m. to 9:00 a.m. and 4:00 p.m. to 6:00 p.m. in accordance with typical practice and to be consistent with ITE's *Trip Generation Manual*. Effort was made to collect the morning and afternoon data for each particular site during the same day, but human resource constraints forced some data to be collected on different days. All collection days were deemed 'typical weekdays' and it was assumed that data could acceptably be collected on different days.

Prior to beginning the morning data collection period, the quantity of parked vehicles was collected. The quantity of entering and exiting vehicular trips, transit riders, pedestrians, and bicyclists was collected in fifteen minute intervals. One data collector was positioned at each entrance and effort was made to include pedestrians and bicyclists that entered and exited away from vehicular entrances. Auburn University's Tiger Transit provided transit ridership data for the Auburn data collection sites. Clemson's Clemson Area Transit services all of the study sites, but is not affiliated with the university and did not assist in data collection. Tuscaloosa's Crimson Ride services some of the study sites but did not assist in data collection. In the event that all data could not be accurately collected, preference was given to ensure that all vehicular trips were captured.

The data collection sites and their addresses are shown in Tables 3.3.1 to 3.3.3. The Auburn University data collection sites are all in Auburn, Alabama and the University of Alabama data collection sites are all in Tuscaloosa, Alabama. The Clemson University data collection sites are in Clemson, South Carolina or the nearby town of Central, South Carolina. The maps of the sites are shown in Figures 3.3.1 to

3.3.2. These figures were developed using the Geographic Information Systems (GIS) capabilities provided by each city.

Table 3.3.1: Data Collection Sites at Auburn University

Site	**Address**	**Map Number (on Figure 3.1)**
Creekside	650 Dekalb Street	1
Eagles West	700 West Magnolia Avenue	2
The Edge	1114 South College Street	3
Exchange	300 East Longleaf Drive	4
Garden District	190 East University Drive	5
Legacy	1131 South College Street	6
Reserve	1255 South College Street	7
Southern Edge	1385 South Donahue Drive	8
Two 21	221 Armstrong Street	9
University Heights	202 West Longleaf Drive	10
University Village	211 West Longleaf Drive	11
Veranda	626 Shug Jordan Parkway	12
The View	340 North Donahue Drive	13

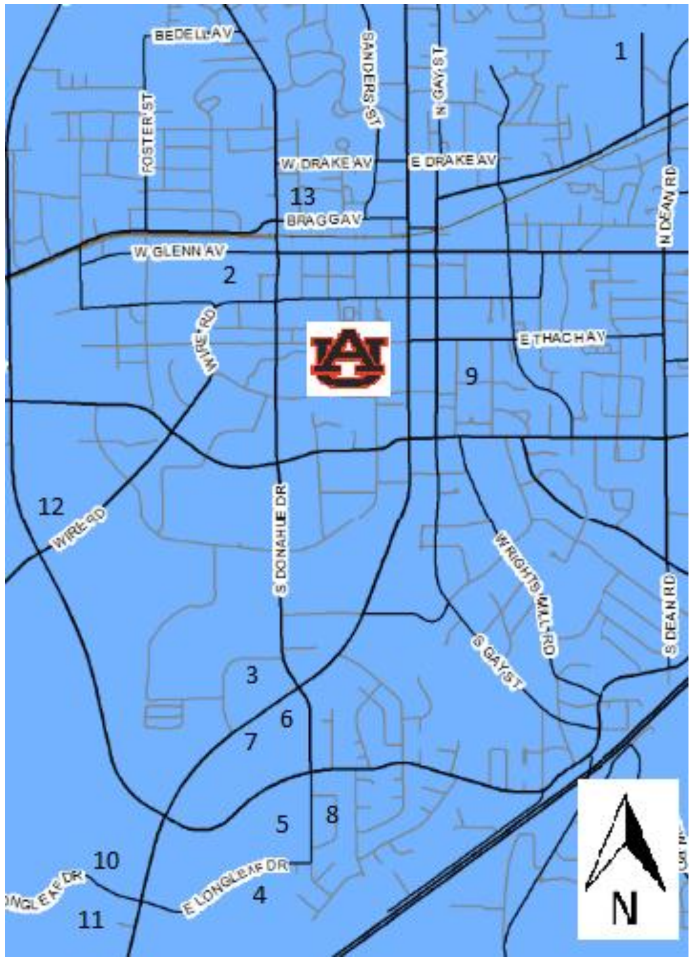

Figure 3.3.1: Map of Auburn, Alabama Data Collection Sites

Table 3.3.2: Data Collection Sites at Clemson University

Site	Address	Map Number (on Figure 3.2)
Heritage at Riverwood	105 Heritage Riverwood Drive, Central	1
Heritage Point	811 Issaqueena Trail, Clemson	2
Lemans	806 College Avenue, Clemson	3
Pointe at Clemson	700 Berkeley Place Circle, Clemson	4
Reserve	103 Sumter Lane, Central	5
Tiger Town Village	387 College Avenue, Clemson	6
University Village	103 University Village Drive, Central	7

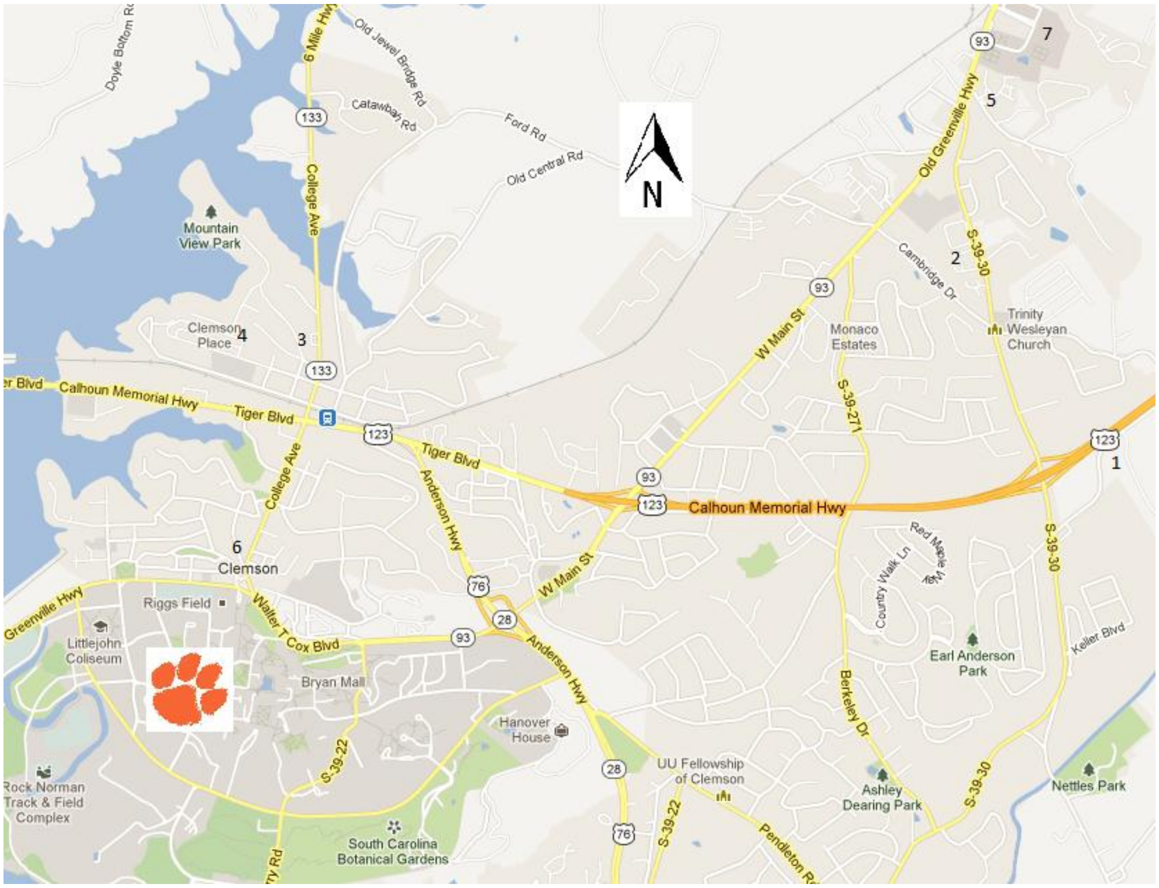

Figure 3.3.2: Map of Clemson, South Carolina Data Collection Sites

Table 3.3.3: Data Collection Sites at the University of Alabama

Site	**Address**	**Map Number (on Figure 3.3)**
Bluffs	427 7th Avenue NE	1
Campus Way	301 Helen Keller Boulevard	2
Canterbury	1108 14th Avenue	3
Crimson Place	600 13th Street	4
Houndstooth	700 15th Street	5
Point O View	1130 Jack Warner Parkway NE	6

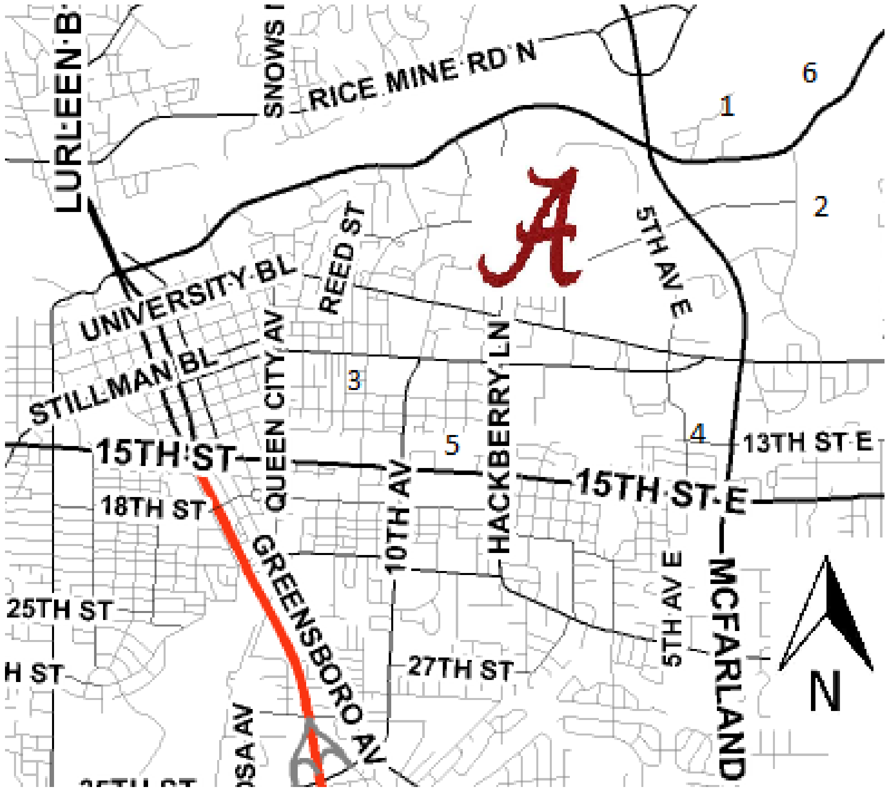

Figure 3.3.3: Map of Tuscaloosa, Alabama Data Collection Sites

Twenty-six study sites have been included in this study. ITE's Land Use 220 currently has 78 studies for the morning period and 90 studies for the afternoon period. There is some concern that the differences in sample sizes will affect the data analysis. However, twenty-six study sites is sufficient for developing trip generation models similar to those developed by ITE.

3.4 Data Analysis

3.4.1 Directional Distribution

The peak hour is the set of four consecutive fifteen minute periods that result in the highest total of combined entering and exiting vehicular trips. The peak hour was identified from the data collected for each site for both the morning and afternoon peak periods. The directional distributions of each data collection site were found. An average of the percent entering and exiting for both the morning and afternoon periods was found for each city, as well as a total average for all data collection sites. A weighted average, in which the value associated with each site is weighted by the number of dwelling units in that site, was also found for the separate cities as well as a total for all sites. The range and standard deviation was found for the average percent entering and exiting. The equation for standard deviation is shown in Equation 3.4.1.

$$\text{Standard Deviation} = \sqrt{\frac{\sum(x-\bar{x})^2}{n-1}} \qquad (3.4.1)$$

Where

x = each individual value

$\bar{x}$ = the average value

n = total observations

3.4.2 Trip Generation Rates

The peak hour of adjacent street traffic plots from ITE's *Trip Generation* Land Use 220 are shown in Figures 3.4.1 and 3.4.2. These plots are a function of the number of dwelling units versus the average vehicle trip ends, or the number of trips generated. ITE's *Trip Generation Manual* provides the number of studies, the average number of dwelling units, the directional distribution, the average rate, the range of rates, and the standard deviation of the rates. The average vehicle-trip rate is the weighted average vehicle-trip rate (citation). A fitted linear regression curve and the coefficient of determination, R^2, are provided.

Apartment
(220)

Average Vehicle Trip Ends vs: Dwelling Units
On a: Weekday,
Peak Hour of Adjacent Street Traffic,
One Hour Between 7 and 9 a.m.

Number of Studies: 78
Avg. Number of Dwelling Units: 235
Directional Distribution: 20% entering, 80% exiting

Trip Generation per Dwelling Unit

Average Rate	Range of Rates	Standard Deviation
0.51	0.10 - 1.02	0.73

Data Plot and Equation

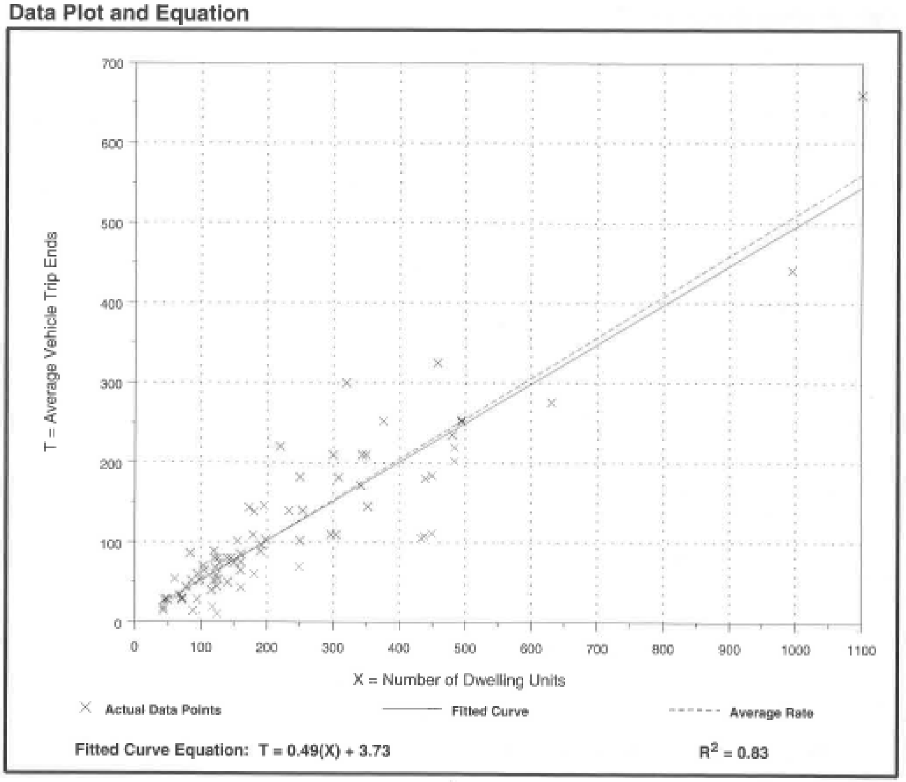

Figure 3.4.1: Land Use 220 Morning Peak Hour of Adjacent Street Traffic plot
Source: ITE 2012

Apartment
(220)

Average Vehicle Trip Ends vs: Dwelling Units
On a: Weekday,
Peak Hour of Adjacent Street Traffic,
One Hour Between 4 and 6 p.m.

Number of Studies: 90
Avg. Number of Dwelling Units: 233
Directional Distribution: 65% entering, 35% exiting

Trip Generation per Dwelling Unit

Average Rate	Range of Rates	Standard Deviation
0.62	0.10 - 1.64	0.82

Data Plot and Equation

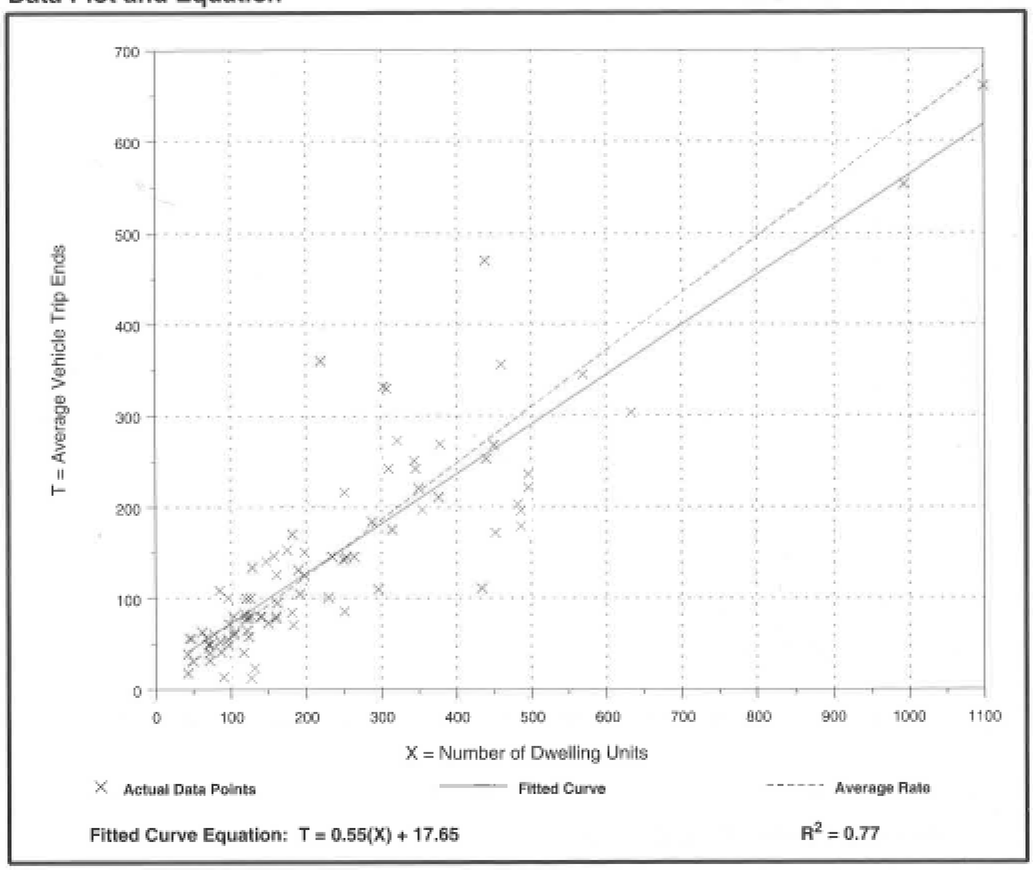

Figure 3.4.2: Land Use 220 Evening Peak Hour of Adjacent Street Traffic Plot
Source: ITE 2012

The number of units in each data collection site was used to determine the trip generation rates for the morning and evening peak hours. The average, range, and standard deviation were found for the trip generation rates among all sites. The rate is shown in Equation 3.4.2 and expressed in trips per dwelling unit.

$$\text{Trip Generation Rate} = \frac{\textit{Peak Hour Trips}}{\textit{Dwelling Units in Data Collection Site}} \qquad (3.4.2)$$

A model was then developed using half of the collected data points and followed the same format as the plots in ITE's *Trip Generation* report. This model is hereafter referred to as the predictive model. The number of units for each data collection site was graphed on the x-axis as the independent variable and the number of vehicle-trips was graphed on the y-axis as the dependent variable. A linear trend line and the coefficient of determination, R^2, were fit to each plot. R^2 is a value between 0 and 1 that indicates the extent to which the model explains the variability in the data.

The data collection sites used for the predictive model were determined with the use of a random number generator. Approximately half of the data collection sites from each city, thirteen in total, were used. The data collection sites used to develop the model are shown in Table 3.4.1.

Table 3.4.1: Data Collection Sites Used to Develop a Trip Generation Model

Site	**City**
Reserve	Auburn
Veranda	Auburn
University Heights	Auburn
University Village	Auburn
Creekside	Auburn
Exchange	Auburn
Edge	Auburn
Tiger Town Village	Clemson
Heritage at Riverwood	Clemson
Lemans	Clemson
Campus Way	Tuscaloosa
Point O View	Tuscaloosa
Canterbury	Tuscaloosa

The remaining half of the data collection sites was used to check the accuracy of the predictive model. The predicted number of vehicle-trips was determined for each of these sites using the linear trend line equations from ITE's *Trip Generation Manual* and the predictive model developed herein. For each site, the predicted vehicle-trips were found by using the actual number of dwelling units for the independent variable in the trip generation equation.

A paired, two-sided t-test was conducted to determine whether there was a statistically significant difference in the vehicle-trips predicted by the two models. The paired t-test was used to directly compare the prediction from each model for each data collection site. The two-sided t-test was used to account for the possibility that the predicted values could be either more than or less than the actual counts. The null hypothesis was that the difference between means for the pairs was zero. 95%

confidence was assumed and a corresponding p-value of 0.05 was used to reject the null hypothesis.

Two statistical analyses, the mean absolute percentage error (MAPE) and root mean square error (RMSE), were run to determine the accuracy of the two models with respect the actual collected trips. The equations for these two analyses are shown in equations 3.4.3 and 3.4.4.

$$\text{MAPE} = \frac{100\%}{n} \sum_{i=1}^{n} \left| \frac{P_t - A_t}{P_t} \right| \tag{3.4.3}$$

$$\text{RMSE} = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (P_t - A_t)^2} \tag{3.4.4}$$

Where

n = total observations

P_t = predicted vehicle-trips

A_t = observed vehicle-trips.

These two statistical analyses were used to provide additional insight and offer a different method of comparing models than the coefficient of determination, specifically one that evaluates the predictive accuracy of the models. The root mean square error is very sensitive to large errors as it gives the large errors a large weight. The mean absolute percentage error does not give such a disproportionate weight to large errors and is the better statistic if random outliers are not an issue. The root mean square error produces results that are inversely similar to the coefficient of determination. As R^2 increases, the root mean square error should decrease. All three analyses produce different statistics and should be considered in the overall evaluation of the models.

3.4.3 Parking Generation

Data collectors were asked to count the number of parked vehicles at each site prior to collecting the morning peak period trip generation data. This data set would be compared to the average peak period parking demand versus dwelling units for weekday suburban locations for Land Use 221: Low/Mid-Rise Apartments in ITE's *Parking Generation* report, 4th edition. Land Use 220: Apartments is not included in the *Parking Generation* report. Data collection occurred on typical weekdays and the three cities used for data collection share more similar characteristics with suburban locations rather than urban locations. The data in the report for Land Use 221, was collected between 12:00 a.m. and 5:00 a.m. to ensure that as many of residents' vehicles as possible are parked at the site. For this study, the assumption was made that this period of valid data collection could be extended to 7:00 a.m. due to typical students' behaviors and travel patterns. This reduced the human resources needed for data collection. Parking counts were only collected at seventeen locations for reasons ranging from data collectors not arriving at the site with enough time to accurately count parked vehicles to data collectors not being able to count parked vehicles within gated apartment complexes. The chart in *Parking Generation* for Land Use 221, weekday suburban, includes twenty-one study sites. The seventeen sites in this study are provided in Table 3.4.2.

Table 3.4.2: Parking Generation Study Sites

Site	**City**
Bluffs	Tuscaloosa
Campus Way	Tuscaloosa
Canterbury	Tuscaloosa
Eagles West	Auburn
Edge	Auburn
Garden District	Auburn
Heritage at Riverwood	Clemson
Heritage Point	Clemson
Legacy	Auburn
Point O View	Tuscaloosa
Reserve	Auburn
Southern Edge	Auburn
The View	Auburn
Two 21	Auburn
University Heights	Auburn
University Village	Auburn
Veranda	Auburn

In accordance with the data provided in the *Parking Generation* report, the average size of the study sites, in dwelling units, was determined. The peak period parking demand was found as a ratio of the number of parked vehicles per dwelling unit. The average peak period parking demand among all sites is the average of the individual peak period parking demands and not a weighted average, as is used for the *Trip Generation Manual*. The standard deviation, coefficient of variations, range, 85th

percentile, and 33rd percentile of the peak period parking demands was found. The 85th percentile is the point at which 85 percent of the values fall at or below. The 85th and 33rd percentiles are not intended to recommend a policy, but are to be used as quantitative references.

Similarly to the trip generation analysis, a predictive model was created using approximately half (nine) of the data collection sites chosen with the use of a random number generator. The individual collected data points were plotted similarly to the procedure used in the *Parking Generation* report. The independent variable, number of dwelling units, was plotted on the x-axis. The dependent variable, the number of parked vehicles, was plotted on the y-axis. A linear trend line was plotted, which resulted in a fitted equation and a resulting coefficient of determination. The sites used to develop the predictive model are shown in Table 3.4.3.

Table 3.4.3: Data Collection Sites Used to Develop a Parking Generation Model

Site	**City**
Garden District	Auburn
University Village	Auburn
Two 21	Auburn
The View	Auburn
Eagles West	Auburn
Edge	Auburn
Heritage Point	Clemson
Campus Way	Tuscaloosa
Canterbury	Tuscaloosa

The same statistical analyses as previously mentioned in Section 3.4.2 for the trip generation model validation were also used for the parking generation model.

3.4.4 Multiple-Regression Modeling

Linear regression modeling can be performed using multiple independent variables. Additional data were obtained regarding the twenty-six data collection sites with the hopes that a more specific model could provide a more accurate estimation of generated trips. The additional data collected included the distance in miles from the collection site to the center of campus and the average rent of the units in housing development. For the purpose of uniformity across the three cities, the library at each university was declared the center of campus. Other characteristics were considered, including the frequency and length of a transit trip and the number of total bedrooms in a housing development. It was initially assumed that an increase in the number of bedrooms would have a positive effect on the number of vehicle trips, as the number of bedrooms gives a clearer picture of the total occupancy of a unit. Transit data was expected to have a significant influence of vehicular travel as well. A good transit system will discourage vehicular travel, so higher frequencies of transit as well as shorter trip times should have a negative effect on vehicular travel.

Transit data fluctuated severely and was not available to similar precision between cities. The number of bedrooms was not available for each housing development. A regression model with multiple independent variables was still conducted for experimental purposes, but not expected to produce an accurate model for predicting. Both morning and afternoon trips were modeled using SPSS for every possible combination of the following three variables: average rent, total units, and distance from the center of campus. Based on a 95% confidence level, any model with a p-value greater than 0.05 was considered to be unacceptable.

3.4.5 Mode Split

Transit ridership counts were collected by Tiger Transit, the Auburn University bus system, at several of the data collection sites. These counts were collected the same day as the trip generation data collection. Tiger Transit was able to provide data for seven of the data collection sites. The data collection sites with transit ridership counts are shown in Table 3.4.4. This data was provided in hour-increments throughout the day. Peak hour volumes could not be determined because data was not separated into fifteen-minute increments.

Table 3.4.4: Data Collection Sites with Transit Ridership Data

Site
Edge
Exchange
Garden District
Reserve
Southern Edge
University Village
Veranda

Vehicle, pedestrian, and bicycle counts were collected between 7:00 a.m. and 9:00 a.m. and between 4:00 p.m. and 6:00 p.m. Because the transit ridership data was not available in fifteen-minute increments, the mode choice for each site was analyzed for the entire morning period, between 7:00 a.m. and 9:00 a.m., and evening period, between

4:00 p.m. and 6:00 p.m. In the absence of vehicle-occupancy data, an occupancy rate of 1.0 was assumed for all vehicular-trips.

The collected data was used to determine the percentages of the usage of each mode of travel for the morning and evening periods. Within each period, the mode choice for both entering and exiting was also determined. While the data for transit riders, bicyclists, and pedestrians were all collected to indicate exactly how many individuals utilized those modes, the total number of vehicles was collected. The number of vehicles must be converted into the number of people traveling by vehicle, using vehicle occupancy rates. However, specific vehicle occupancy data was not available. Because student-oriented housing is a very specific land-use, there is not enough published data to support a vehicle occupancy rate assumption. Therefore, a default value of one person per vehicle was assumed. This is a very conservative assumption and will result in the lowest possible number of person-trips for the vehicle mode. Therefore, the true mode split will have more persons traveling via vehicle than the calculations represent.

3.5 Summary of Methodology

Data were collected in three college towns and organized to develop models to predict trip generation and parking generation for student-oriented housing developments. Two trip generation models were created, a morning and evening peak period of adjacent street traffic. The parking generation model was derived from data that was collected prior to 7:00 a.m. Each model was developed using approximately half of the collected data. The remaining halves of the data were used to compare this model to the existing models in ITE's publications. Pedestrian, bicyclist, and transit rider counts were also collected for several of the developments to analyze the mode choice. Additional variables were researched, such as average rent, distance from campus, transit accessibility, and the number of bedrooms. Transit accessibility and the number of bedrooms were not easily determined. A multiple linear regression model with several independent variables was tested using average rent and distance from campus.

Chapter Four

Results

Chapter four contains the results of the study outlined in the preceding chapter, beginning with the directional distribution of collected traffic data from the twenty-six student-oriented housing developments. The trip generation rates were determined for the collected data. Vehicle-trip generation models for morning and evening peak hours were developed using collected data from thirteen of the twenty-six sites and validated with the data from the remaining thirteen sites. The predictive model was compared to the model in ITE's *Trip Generation Manual* for Land Use 220. A paired two-tailed t-test was used to verify that the two models were statistically different. The two-tailed t-test was chosen to account for the possibility that the values could be either greater than or less than the comparison value. The predicted trips for each model were compared to the actual collected trips using root mean square error and mean absolute percentage error. The parking demand of seventeen data collection sites was analyzed similarly to ITE's *Parking Generation* report. A parking demand model was developed using roughly half of the collected data and validated similarly to the trip generation model.

In addition to vehicle-trips, pedestrians, bicyclists, and transit riders were also collected at the majority of the study sites in Auburn. This data was used to determine the mode choice of these developments. Additional models were developed using multiple independent variables to test whether or not other variables could help better predict vehicle-trips. These additional variables include the study sites' average rent and distance from the center of campus.

4.1 Directional Distribution

The peak hour of each data collection site was determined for both the morning and evening peak periods. The weighted averages of the directional distributions were found for each city, and overall, and are shown in Table 4.1.1. The weighted average is a sum of the total entering or exiting vehicle trips divided by the sum of the total trips across all sites within the city and overall. This method is used to ensure that each site's contribution to the total is proportional to the number of trips observed for each site.

Table 4.1.1: Weighted Averages of the Directional Distributions

			Morning Peak Period		Evening Peak Period	
	Collection Sites	Dwelling Units	Entering	Exiting	Entering	Exiting
Auburn	13	2538	34%	66%	49%	51%
Clemson	7	1209	16%	84%	57%	43%
Tuscaloosa	6	828	18%	82%	54%	46%
Overall			**25%**	**75 %**	**52%**	**48%**
ITE 220			**20%**	**80 %**	**65%**	**35%**

For Land Use 220 (Apartment), ITE's *Trip Generation Manual* reports a 20% entering and 80% exiting directional distribution during the morning peak period for the peak hour of adjacent street traffic. While the data from Clemson and Tuscaloosa represent similar patterns between those cities during the morning peak period, the data collected in Auburn reflect a higher percentage of entering vehicles than suggested by Land Use 220. Once combined across the three cities, the overall morning directional distribution follows a reasonably similar trend as the data published in ITE's *Trip Generation Manual* for Land Use 220.

Once again, the data collected in Auburn do not follow the same trends as Clemson and Tuscaloosa during the evening peak period, and in all three cities the trends differ considerably from ITE's *Trip Generation Manual*, which reports a 65% entering and 35% exiting directional distribution for the evening peak period. The overall directional distribution across all 26 sites in all three cities is 52% entering and 48% exiting. The data collected in Auburn indicate that more vehicles are exiting student-oriented housing developments during the evening peak period than are entering the developments. The directional distribution is very close to an even split but still suggests, in general across the three cities, that more vehicles are entering than exiting during the evening peak period. The directional distribution of the collected data during the evening peak period is considerably different than the directional distribution in ITE's *Trip Generation Manual*.

Table 4.1.2 presents the ranges of the directional distributions among the twenty-six sites. The ranges are separated by city, and an overall range is also given. The wide ranges demonstrate the variability within the data. The data show that there is more variability within the Auburn data collection sites, but this could be due in part to the fact that data were collected at more sites within Auburn.

Table 4.1.2: Ranges of the Directional Distributions

	Morning Peak Period		Evening Peak Period	
	Entering	Exiting	Entering	Exiting
Auburn	14% - 47%	52% - 86%	37% - 56%	44% - 63%
Clemson	11% - 28%	72% - 89%	54% - 65 %	35% - 46%
Tuscaloosa	13% - 35%	65% - 87 %	45% - 58%	42% - 55%
Overall	**11% - 47%**	**52% - 89%**	**37% - 65%**	**35% - 63%**

Table 4.1.3: Standard Deviations of the Directional Distributions

	Morning Peak Period	Evening Peak Period
Auburn	9.3%	5.6%
Clemson	5.3%	4.3%
Tuscaloosa	8.7%	5.6%
Overall	**11.1%**	**6.7%**

The standard deviations of the directional distributions presented in Table 4.1.3 show that there is more variability in the Auburn data than the other two cities. Strangely enough, there is considerably less variability in the evening peak period than the morning peak period even though there is a larger difference in the collected directional distribution as opposed to the data reported in ITE's *Trip Generation Manual* for the category "Apartments".

4.2 Trip Generation Rates

A vehicle-trip generation rate was found for each data collection site for both the morning and evening peak periods. The rate is expressed in vehicle-trips per dwelling unit. The range of the rates, standard deviations of the rates, and the number of sites are shown in Tables 4.2.1 and 4.2.2 for each city and overall. The average rate is the weighted average rate in accordance with the *Trip Generation Manual User's Guide* (ITE 2008). Similar to the methodology used to analyze directional distribution, this ensures that the contribution of each collection site is proportional to both the number of observed trips and the number of dwelling units.

Table 4.2.1: Trip Generation Rates for the Morning Peak Hour (vehicle-trips/dwelling unit)

	Average Rate	Range	Standard Deviation	Number of Sites	Coefficient of Variation
Auburn	0.41	0.26 - 1.00	0.20	13	0.49
Clemson	0.59	0.14 - 0.85	0.26	7	0.44
Tuscaloosa	0.45	0.21 - 0.73	0.19	5	0.42
Overall	**0.47**	**0.14 - 1.00**	**0.21**	**25**	**0.45**
ITE 220	**0.51**	**0.10 - 1.02**	**0.73**	**78**	**1.43**

Table 4.2.2: Trip Generation Rates for the Evening Peak Hour (vehicle-trips/dwelling unit)

	Average Rate	Range	Standard Deviation	Number of Sites	Coefficient of Variation
Auburn	0.95	0.74 - 1.53	0.25	13	0.26
Clemson	0.88	0.45 - 1.27	0.34	7	0.39
Tuscaloosa	0.99	0.41 - 1.58	0.38	6	0.38
Overall	**0.94**	**0.41 - 1.58**	**0.31**	**26**	**0.33**
ITE 220	**0.62**	**0.10 – 1.64**	**0.82**	**90**	**1.32**

As shown in Table 4.2.1, the average vehicle-trip rates for the morning peak period range from 0.41 to 0.59 trips per unit for the three cities. The data collected in Clemson shows a higher weighted average trip generation rate than the other two cities. The standard deviation for the Clemson data is also larger than the other two cities. The morning peak hour weighted average trip generation rate for all three cities is 0.47 trips per dwelling unit, compared to 0.51 trips per dwelling unit as reported in ITE's *Trip Generation Manual* for the land use category "Apartments".

The data in ITE's *Trip Generation Manual* for the morning peak period has a range of 0.10 to 1.02 trips per dwelling unit. The wide range may be attributed in part to the larger sample size. ITE reports a standard deviation of 0.73, while the collected data has a standard deviation of 0.21. This results in a coefficient of variation of 1.43 for ITE's data, compared to 0.45 for the collected data.

The evening peak hour does not follow the same trend as the morning peak hour. The average vehicle-trip rates for the evening peak period range from 0.88 to 0.99 trips per unit for the three cities as can be seen in Table 4.2.2. The data suggest that Clemson has the fewest trips generated per unit. Once again, Auburn and Tuscaloosa show similar weighted average vehicle-trip rates. The overall evening peak hour weighted trip generation rate is 0.94 trips per dwelling unit, compared to 0.62 trips per dwelling unit as reported in ITE's *Trip Generation Manual* for the land use category "Apartments".

The data in ITE's *Trip Generation Manual* for the evening peak period has a range of 0.10 to 1.64 trips per dwelling unit. The collected data has a range of 0.41 to 1.58 trips per dwelling unit. ITE's data has a standard deviation of 0.82, compared to the collected data's standard deviation of 0.31. ITE's data has a coefficient of variation of 1.32, while the collected data has a coefficient of variation of 0.33.

A model was developed to estimate the number of peak hour vehicle-trips generated by student-oriented housing developments. The model was developed using approximately half of the collected data points from each city and was plotted in the same format as the plots in ITE's *Trip Generation*. The number of dwelling units is the independent variable and is placed on the x-axis. The number of vehicular trips is the dependent variable and is plotted on the y-axis. The morning and evening peak period plots for the model are shown in Figures 4.2.1 and 4.2.1, respectively.

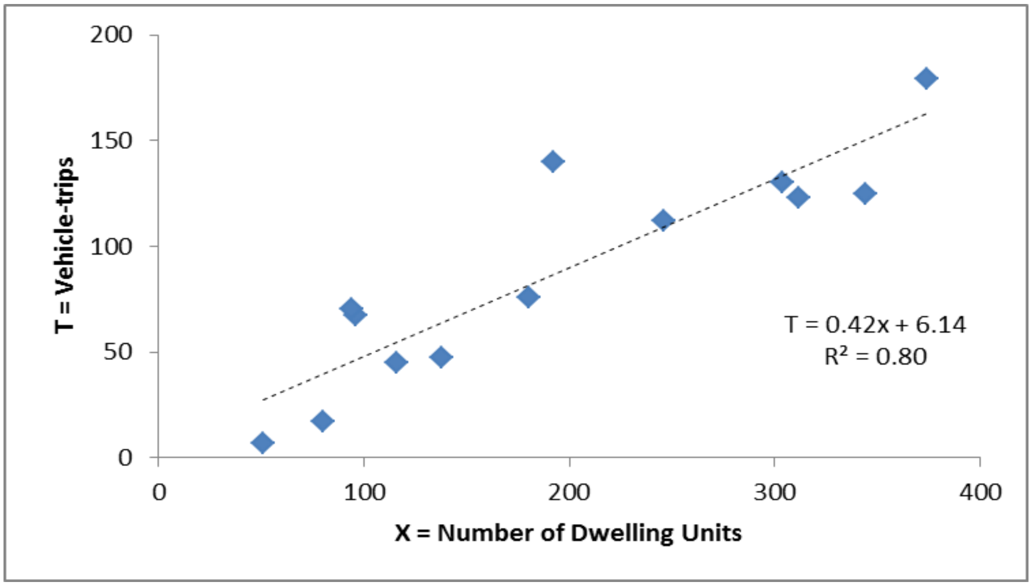

Figure 4.2.1: Morning Peak Hour Trip Generation Model

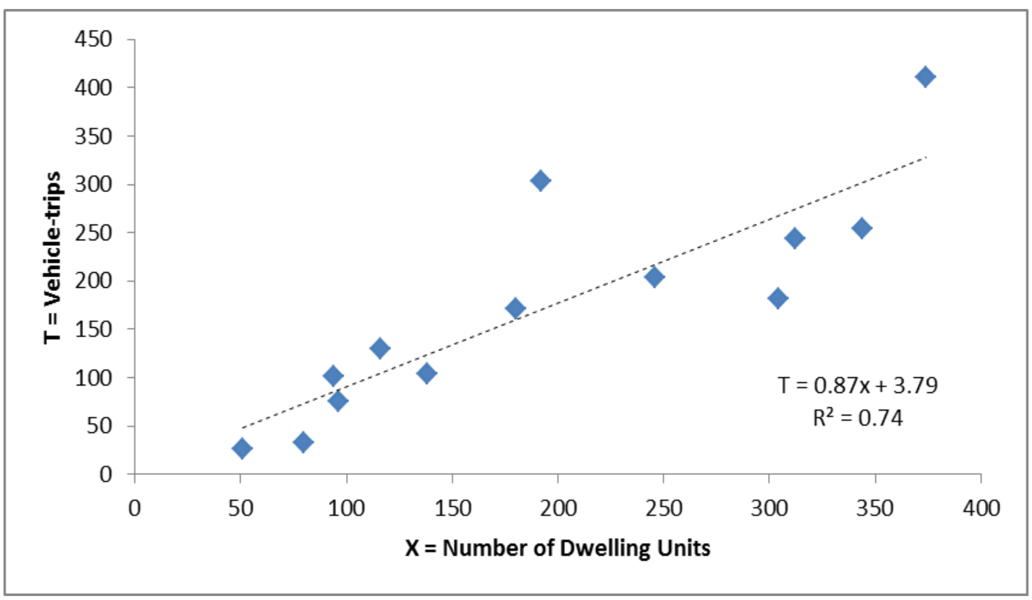

Figure 4.2.2: Evening Peak Hour Trip Generation Model

A linear regression model was developed for both the morning and evening models. The morning peak period resulted in a best fit equation of T = 0.42 (X) + 6.14 with an R^2 value of 0.80. The evening peak period resulted in a best fit equation of T = 0.87 (X) + 3.79 with an R^2 value of 0.74. The best fit equations were used to determine the predicted number of trips for the data points being used to evaluate the predictive models. A prediction for the number of trips using the model was determined for the sites not used in development of the predictive model along with a predicted number of trips using ITE's *Trip Generation* Land Use 220. The predicted trips are shown in Table 4.2.3 along with the actual collected trips.

Table 4.2.3: Actual and Predicted Trips for Sites Used For Testing Validity

		Morning			**Evening**		
	City	**Actual Trips**	**ITE Prediction**	**Model Prediction**	**Actual Trips**	**ITE Prediction**	**Model Prediction**
Legacy	Auburn	73	88	78	170	112	153
Garden District	Auburn	59	104	92	228	130	181
Two 21	Auburn	48	80	71	200	103	139
The View	Auburn	14	21	21	55	37	35
Eagles West	Auburn	52	102	90	156	128	178
Southern Edge	Auburn	40	23	23	55	40	38
University Village	Clemson	265	156	136	377	189	273
Heritage Point	Clemson	58	90	80	80	114	156
Reserve	Clemson	123	90	80	173	115	157
Pointe at Clemson	Clemson	65	51	46	122	71	87
Houndstooth	Tuscaloosa	47	67	61	109	89	116
Crimson Place	Tuscaloosa	61	76	68	144	99	132
Bluffs	Tuscaloosa				127	95	125

Three statistical analyses were conducted to compare the vehicle-trips estimated by the predictive model with the trips estimated by the model provided in ITE's *Trip Generation Manual*. A paired t-test was used to determine if the trips predicted by ITE's model were statistically different from the trips predicted by the model developed from the collected data. The null hypothesis was that the predicted trips were not statistically different from each other. The resulting p-values for the morning and evening peak periods were 0.00017 and 0.00014, respectively. Because each p-value is less than 0.05, the null hypothesis can be rejected. There is a statistically significant difference between the trips predicted by the ITE model and the model created from the collected data.

A mean absolute percentage error (MAPE) and a root mean square error (RMSE) were also developed for the predictions for both models. The resulting values for both the mean absolute percentage error and the root mean square error are shown in Table 4.2.4.

Table 4.2.4: MAPE and RMSE Values for Model Comparison

	Morning		**Evening**	
Model	**MAPE**	**RMSE (trips)**	**MAPE**	**RMSE (trips)**
ITE *Trip Generation Manual*	39.60%	41.78	52.48%	73.18
New Model	39.55%	43.69	26.76%	44.41

The mean absolute percentage error and the root mean square error for the morning peak period are very similar for both models and therefore, it cannot be concluded that the model created from the collected data is any more accurate than the existing model in ITE's *Trip Generation*. However, the model created from the collected data shows increased accuracy for the evening peak period.

Figure 4.2.3 presents a plot containing all collected data points for the evening peak period.

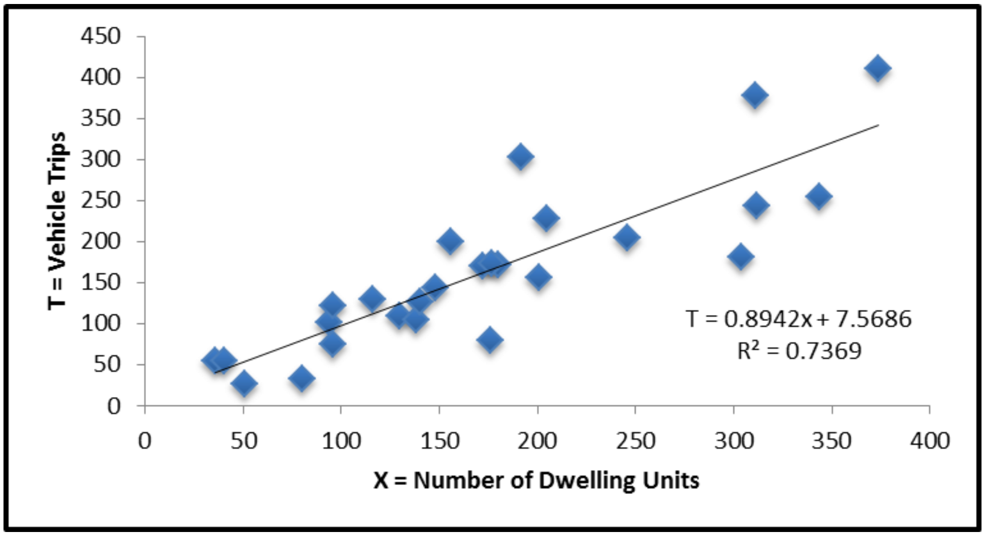

Figure 4.2.3: Evening Peak Period Plot Containing All Collected Data

The linear regression model developed for the plot containing all collected data is T = 0.89 (X) + 7.57, with an R^2 value of 0.74. Because all collected data were used to develop this plot, the accuracy of this model could not be tested. Additional data collection would be required to evaluate the performance of this model.

It must noted that the models created in this study include pre-selection bias. The sample used to create these models is very specific as all collection sites are student-oriented housing developments and were collected in the spring of 2012. The data used for ITE's model comes from a wider sample, across many demographic groups. The data in the *Trip Generation Manual* consists of a wider range of apartment developments and has been collected over several decades. If specific information about ITE's data was available, a more accurate prediction could be made by removing data points not associated with the subject demographic group.

4.3: Parking Generation

The seventeen sites with parking counts were analyzed similarly to the data in the 4th edition of ITE's *Parking Generation* report. The reported statistics for Land Use 221:

Low/Mid-Rise Apartment for weekdays in a suburban location are shown in Table 4.3.1 along with the statistics for the collected data. The parking generation plot for ITE's *Parking Generation* Land Use 221, weekday suburban, is shown in Figure 4.3.1.

The average size of the study sites for the data collected in the current study was considerably smaller than the average size of the study sites in Land Use 221. In fact, only one data collection site has more dwelling units than Land Use 221's average of 311 dwelling units. The average peak period parking demand in vehicles per dwelling unit for the collected data was 50% greater than the average peak period parking demand for Land Use 221. The data collected herein has a larger standard deviation, which can be attributed, in part, to the larger mean. Other factors could include the differences in site locations, availability to transit service, and the number of bedrooms per dwelling unit.

Land Use: 221
Low/Mid-Rise Apartment

Average Peak Period Parking Demand vs. Dwelling Units
On a: Weekday
Location: Suburban

Statistic	Peak Period Demand
Peak Period	12:00–5:00 a.m.
Number of Study Sites	21
Average Size of Study Sites	311 dwelling units
Average Peak Period Parking Demand	1.23 vehicles per dwelling unit
Standard Deviation	0.32
Coefficient of Variation	21%
95% Confidence Interval	1.10–1.37 vehicles per dwelling unit
Range	0.59–1.94 vehicles per dwelling unit
85th Percentile	1.94 vehicles per dwelling unit
33rd Percentile	0.68 vehicles per dwelling unit

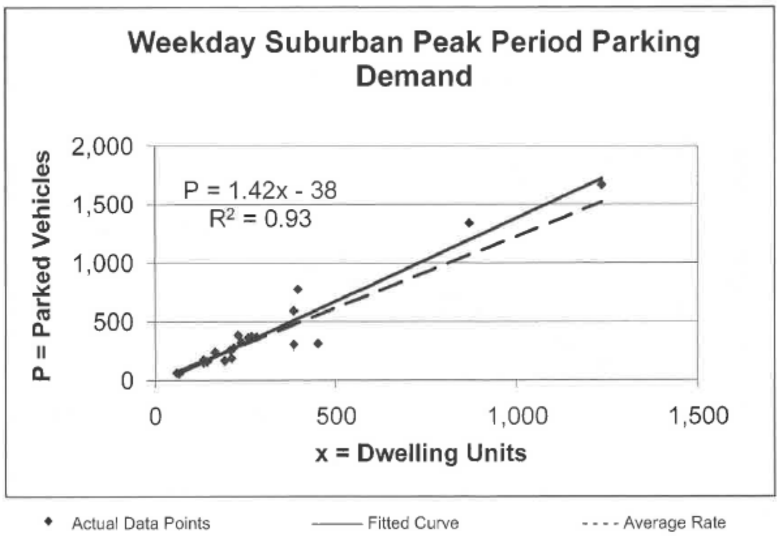

Figure 4.3.1: Land Use 221 Weekday Suburban Parking Demand
Source: ITE, 2012

Table 4.3.1: Parking Demand Statistics for Land Use 221 and the Collected Data

Statistics	Land Use 221	Collected Data
Number of Study Sites	21	17
Average Size of Study Sites (dwelling units)	311	166
Average Peak Period Parking Demand (vehicles per dwelling unit)	1.23	1.84
Standard Deviation	0.32	0.59
Coefficient of Variation	26%	32%
Range (vehicles per dwelling unit)	0.59 – 1.94	0.96 - 2.62
85th Percentile (vehicles per dwelling unit)	1.94 vehicles	2.62 vehicles
33rd Percentile (vehicles per dwelling unit)	0.68 vehicles	1.60 vehicles

Similarly to the trip generation data, a model was created using half of the collected parking data. The model's performance was evaluated using the remaining half of the collected data. The plot for the parking demand model is shown in Figure 4.3.2.

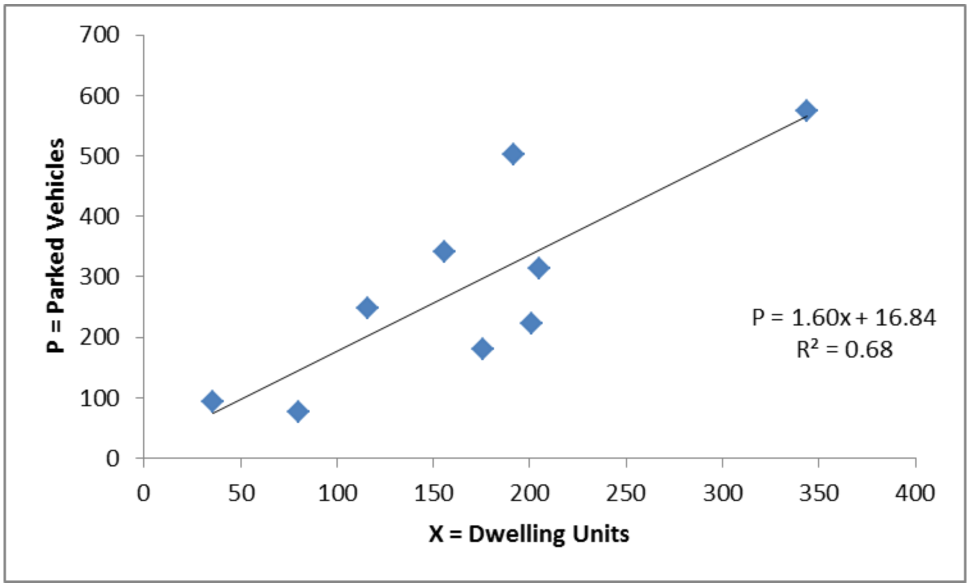

Figure 4.3.2: Parking Demand Model

A linear regression model was developed for the parking demand data collected in this study. The best fit equation is P = 1.60(X) + 16.84, with an R^2 value of 0.68. The best fit equation was used to predict the number of parked vehicles. The prediction using ITE's *Parking Generation* uses the best fit equation of P = 1.42(X) - 38. The actual parked vehicles and predicted vehicles based on both the ITE *Parking Generation* model and the model created from the collected data are shown in Table 4.3.2.

Table 4.3.2: Actual and Predicted Parked Vehicles

Collection Site	**City**	**Units**	**Actual Parked Vehicles**	**Model Prediction**	**ITE Prediction**
Reserve	Auburn	180	347	304	218
Legacy	Auburn	172	304	291	206
Veranda	Auburn	96	264	170	98
University Heights	Auburn	246	432	409	311
Southern Edge	Auburn	40	108	81	19
Heritage at Riverwood	Clemson	304	391	502	394
Point O View	Tuscaloosa	138	218	237	158
Bluffs	Tuscaloosa	140	235	240	161

Three statistical analyses were run to determine if the model better predicted actual parked vehicles than the model provided in ITE's *Parking Generation*. The statistical analyses included mean absolute percentage and root mean square errors comparing the differences between each prediction and the actual collected number of parked vehicles. A paired, two-tailed t-test was used to determine if the two predictions were statistically different. The null hypothesis is that the two predictions are not statistically different.

The mean absolute percentage error of ITE's *Parking Generation* model is 109%, compared to a mean absolute percentage error of 18% for the model created from half the collected data. The root mean square error for ITE's model is 103.3 vehicles, compared to 55.7 vehicles for the model created from the collected data. The t-test reports a p-value of 0.0000008. The null hypothesis can be rejected because the p-value is less than 0.05, implying greater than 95% confidence. Therefore, the two predictions are significantly different from a statistical perspective.

The statistical analyses suggest that the model created from half of the data collected in Auburn, Clemson, and Tuscaloosa better predicts the actual number of parked vehicles amongst the remaining data collected sites than the model provided in ITE's *Parking Generation*. While it cannot be proven, combining all collected data into one model may be more accurate than the previously mentioned model developed from half of the collected data. Figure 4.3.3 presents the plot of all collected data.

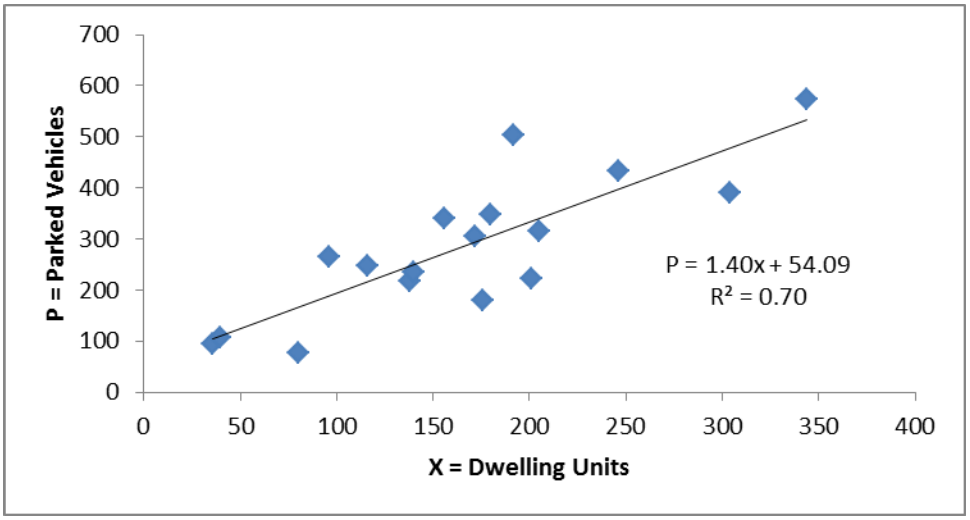

Figure 4.3.3: Parking Demand for All Collection Sites

The fitted equation is P = 1.39 (X) + 54.09, with a coefficient of determination, R^2, of 0.70. ITE's *Parking Generation* fitted equation for Land Use 221 is P = 1.42 (X) – 38 with a coefficient of determination of 0.93. The y-intercept of -38 may underestimate the parking demand of smaller complexes. A y-intercept of 54 could also overestimate the parking demand for these same complexes. Theoretically, the linear trend line should have a set intercept of zero, but the intercept is not set to allow for a higher coefficient of determination. If the linear trend line for the collected data is forced to go through the origin, the resulting fitted equation is P = 1.66 (X) with a coefficient of determination of 0.67.

ITE's *Parking Generation* report does not include any guidance as to the size of the individual units in the study sites. Many of the apartments in Land Use 221's study sites may only have one or two bedrooms. These apartments may also only have one or two residents of driving age per unit. However, student-oriented housing developments frequently have units with three or four bedrooms, all of which may be filled by a vehicle-owning student.

4.4 Multiple Regression Modeling

The models in ITE's publications only have one independent variable a piece. In an effort to determine if additional variables would better predict trip generation, linear regression modeling was performed for every possible combination of three independent variables: average rent per bedroom, total units, and distance to the center of campus. The linear regression modeling was performed for two separate dependent variables: morning vehicle-trips and afternoon vehicle-trips. Several performance measures were considered when assessing the validity of the models. The coefficient of determination, R^2, was considered. A higher R^2 value suggests that the data follows a more reliable pattern than a model with a lower R^2 value. The analysis of variance calculations provide a p-value which expresses the probability of obtaining a test statistic as extreme as the value suggested by the null hypothesis. In this case, a value of 0.05 or lower suggests that the null hypothesis can be rejected at the 95% confidence level. Any model with a p-value greater than 0.05 was not considered.

Of the models created, the highest R^2 value was 0.393. This model had three independent variables: number of dwelling units, distance from the center of campus, and the average rent. The dependent variable was the number of trips during the morning peak period. The resulting equation was Morning Trips = -83.182 + 0.041(Number of Dwelling Units) + 33.270(Distance from the Center of Campus in miles) + 0.2(Average Rent per Bedroom in dollars). However, a t-test indicates that the only variable with any statistical significance was the distance from center of campus. When another model was developed using only the distance from the center of campus as an independent variable, the model, as expected, resulted in a lower R^2 value due to the fact that additional variables increase R^2 values. Unfortunately, the additional variables did not appear to improve upon the models created for this study. There does not appear to be a strong correlation between the distance from campus or the average rent and the trips generated by the developments.

4.5 Mode Split Analysis

In addition to vehicular, bicycle, and pedestrian counts, transit ridership data were collected by Tiger Transit for seven collection sites within Auburn, Alabama. The data were used to determine the distribution of person-trips for each mode of transportation. The periods considered were 7:00 a.m. to 9:00 a.m. and 4:00 p.m. to 6:00 p.m.

Using the default vehicle occupancy rate of one person per vehicle, the percentages of individuals utilizing each mode choice were determined. The mode choice was separated into the morning and evening periods, as well as overall values. An entering and exiting mode split was also determined for both the morning and evening periods. The percentages of individuals utilizing each mode are shown in Table 4.5.1.

Table 4.5.1: Mode Split Analysis

	Morning			**Evening**			
Mode	**Entering**	**Exiting**	**Total**	**Entering**	**Exiting**	**Total**	**Overall**
Vehicles	80.5%	57.1%	63.4%	76.5%	92.3%	83.6%	76.1%
Transit	18.7%	40.6%	34.7%	21.4%	4.9%	14.0%	21.7%
Bicycle	0.0%	0.6%	0.4%	0.6%	1.2%	0.9%	0.7%
Pedestrians	0.8%	1.8%	1.5%	1.6%	1.6%	1.6%	1.5%

As shown in Table 4.5.1, the majority of individuals utilized a private vehicle to enter or exit the studied student-oriented housing developments during the morning and evening peak periods. Because of the conservatively set default vehicle occupancy rate, it is likely that the true percentage of people traveling by vehicle is higher. According to the collected data, the mode choice is significantly different in the evening period as opposed to the morning period. About 84% of trips were taken by vehicle during the evening period, while only approximately 63% of trips were taken by vehicle during the morning period. During both periods, bicycle and pedestrian travel was almost negligible. However, the sites included in this study were an average of 2.3 miles from campus center and sites closer to campus should produce considerably more pedestrian and bicycle trips. Overall, approximately 2% of trips were taken by pedestrians and bicyclists. Bicycle and pedestrian travel did not vary too much between the morning and evening peak periods.

Transit consisted of a significantly larger portion of the morning travel. Approximately 35% of morning trips were taken by transit, as opposed to 14% of evening trips. Despite the morning trips consisting of approximately 60% of the total number of evening trips, the morning period had approximately 150 more transit riders than the evening period.

The difference in transit ridership between the morning and evening peak periods may be attributed in part to student schedules. Many of the students who choose to utilize the transit system will leave for campus during the morning peak period but may return during the early to mid-afternoon due to their class schedules not lasting a full work-day. The transit system's schedule may discourage evening ridership. Less than

5% of the evening exiting trips are taken by transit. The availability of evening on-campus parking may encourage vehicular travel, as students are able to find additional parking spaces after business hours.

The average distance from the center of campus for the seven sites was 2.2 miles, as compared to the 2.3 mile average distance from the center of campus for all sites. Distance from campus may affect mode choice, but the seven sites considered appear to be an accurate representation of the original 26 sites.

4.6 Conclusions of Results

This chapter presented the results of the studies conducted regarding trip generation and parking demand of student-oriented housing developments. Two models were created using the collected data in Auburn, Clemson, and Tuscaloosa and formatted in the same manner as the models in ITE's *Trip Generation Manual*. Each model was created using approximately half the collected data and tested using the other half of the data. The predictive models were compared to ITE's Land Use 220: Apartments in the *Trip Generation Manual*. The statistical analyses indicate that the model created for the morning peak period is not any more accurate than ITE's model, however the model created for the evening peak period shows a considerable increase in accuracy over ITE's model.

A similar process was conducted to model parking demand. A model was created using half of the data and formatted similarly to the models in ITE's *Parking Generation*. The other half of the collected data was used to compare the accuracy of this model to *Parking Generation*'s Land Use 221. According to the statistical analyses, the model created in this study better predicts the parking demand for similar sites.

Additional variables were used to test the feasibility of developing a model with multiple independent variables. In addition the number of dwelling units, the average rent and the distance from the center of campus were quantified and used to develop a model. Of the combinations tested, only three models had suitable p-values ($p < 0.05$) and the highest R^2 value among these models was 0.393. It was decided that these models could not accurately predict trips generated by student-oriented housing developments.

A mode choice analysis was also performed using data from the majority of the sites in Auburn, Alabama. This analysis suggested that the number of pedestrians and bicyclists is relatively negligible compared to the transit and vehicle users for housing developments within a similar range of the sites involved in this study. The average distance from campus of the developments included in the mode choice analysis was 2.3 miles. The percentage of travelers utilizing transit was higher in the morning than in the evening peak period. Therefore, a higher percentage of travelers drove during the evening peak period as opposed to the morning peak period.

Chapter Five

Conclusions and Recommendations

5.1 Conclusions

The research conducted in this study indicates that student-oriented housing demonstrates unique characteristics when compared to traditional residential housing. Prior to this study, there was very little published research regarding the trip generation aspects of student-oriented housing developments on transportation planning. The transportation planning community seems to recognize that not all residential housing developments generate similar traffic patterns. ITE's *Trip Generation Manual* includes land-uses for numerous different types of residential developments. For example, there are several land-uses designated for retirees. The existence of these land-uses, along with the extensive research published on the topic, indicates that age and employment status may have a considerable effect on trip generation.

This study involved the creation of two trip generation models, both a morning and an evening model for the peak hour of the adjacent street traffic. Twenty-six sites in Auburn, Clemson, and Tuscaloosa were studied and the collected dataset was used to create and evaluate predictive models. Half of the data was randomly chosen to create the model and the other half was used for evaluation. The estimated numbers of trips were determined using both the predictive model and ITE's model for Land Use 220. These estimated numbers of trips were then compared to the actual collected number of trips. Three statistical analyses were used to evaluate these models. A paired two-tail t-test was used to test the null hypothesis that the two data sets, the actual and estimated trips, were statistically similar. The null hypothesis was rejected and it was assumed that the trips predicted by the two models were statistically different from each other. Both the morning and evening models showed significant statistical differences between the predictive models developed herein and those provided in ITE’s *Trip Generation Manual*.

The mean absolute percentage error and root mean square error were calculated for the predictions of both models. These errors were used to express the accuracy of each model. The morning models had very similar errors and therefore, it cannot be concluded that the morning predictive model is any more accurate than ITE's model. However, the predictive model for the evening period developed herein had a mean absolute percentage error (MAPE) of 26.76% compared to ITE's MAPE of 52.48%. The root mean square error of the predictive model was 44.41 compared to ITE's RMSE of 73.18. It can be concluded that the predictive model more accurately predicts trips generated by similar student-oriented housing developments.

A similar process was performed for parking demand. Parking data were collected at seventeen sites. Approximately half of the data were used to create a predictive model and the other half of the data were used to evaluate the predictive model and ITE's model in *Parking Generation*. A paired two-tailed t-test suggested that the two models are statistically different. The MAPE of the predictive model was 18%, compared to ITE's 109%. The RMSE of the predictive model was 55.7, compared to ITE's 103.3. The statistical analyses suggest that the predictive model developed herein more accurately predicts the parking demand created by similar student-oriented housing developments than does the applicable model in ITE's *Parking Generation*.

Mode choice data were collected from seven of the sites in Auburn. This dataset included the pedestrian, bicyclist, and transit ridership counts. Due to the low sample size, the findings from this study provide additional narrative but cannot be recommended for future use. The dataset lacked the presence of sites within walking distance of campus and all sites were collected in the same city. The findings from this study indicate that bicyclists and pedestrians represent a very small portion of the travelers. The study sites were an average of 2.3 miles from the center of campus, which most likely had a very strong influence on the mode choice. Vehicles represent the majority of trips taken from these sites during the peak periods. Transit ridership represented about 35% of the travelers during the morning peak period, but only about 14% during the evening peak period. Unfortunately, vehicle occupancy data were not available for this study, so it was assumed that there was one traveler per vehicle.

Additional models were developed to predict trip generation. These models consist of multiple independent variables, such as average rent and distance from the center of campus. These models were studied with the intention of finding a model that would more accurately predict trips generated by student-oriented housing developments. Unfortunately, the models were unable to exhibit enough statistical significance to be further considered.

5.2 Recommendations

Transportation planners should be careful when using published trip generation rates. Trip generation rates can vary greatly by region or size of a city. The demographics of an area and the specific type of development can affect the trip generation rates considerably. While the models created in this study may be better suited for estimating the number of trips generated by an off-campus student-oriented housing development in a typical college town, additional data may need to be collected before these models can be widely accepted. Because of logistical constraints, this study only included college towns in the southeastern United States. The model developed in this study should be used for studies involving college towns similar to the towns used in this study.

In a perfect world, transportation planners should collect trip generation and parking demand data at existing developments that are deemed to be similar in size and location to the proposed development being studied. However, data collection is costly and time consuming. In the effort to save money, planners study pre-existing data to make their decisions. Planners should ensure that the dataset used to build a model is relevant to their study. Outdated data or data from a different setting may not accurately describe the conditions present at a new development. Until more data have been collected and analyzed, planners should proceed with caution when studying any sites related to student-oriented housing developments.

5.3 Recommendations for Future Research

Additional data collection in college towns in different regions of the country would resolve any potential regional bias found in the data of this study. As data points are collected for this proposed land use, transportation planners can use the data with more certainty. There are numerous qualifying college towns in the United States, and many of them have ITE student chapters. Data collection would be more feasible if ITE reached out to these student chapters and expressed a need for assistance.

If logistically possible, twenty-four hour data counts could provide additional information that was not found in this study. A twenty-four hour count could clearly indicate the peak hour of the generator, which could provide more extensive insight to students' travel behavior. Additional data would allow for the creation of models other than those that predict the trips generated during the peak hours of adjacent street traffic.

Additional effort should be made to ensure that the number of total bedrooms for each development can be identified. Using the number of total bedrooms for an independent variable could possibly produce a more accurate model. Collecting vehicular trips should remain the first priority of data collectors, but they should be encouraged to attempt to count all travelers to the best of their ability. If these data are collected more extensively, conclusions could possibly be made regarding the mode choice of student-oriented housing developments. With more data points, efforts can be made to establish a correlation between mode choice and the distance from the center of campus.

The most accurate method for determining trip generation is to study the patterns of similar sites. Future data collection will allow for a wider range of existing data that will help transportation planners complete more accurate trip generation studies. The collected data should be published and shared amongst the transportation engineering community to ensure that the full benefit is achieved.

References

American Association of Retired Persons Public Policy Institute. Fact Sheet 218. April 2011. <http://assets.aarp.org/rgcenter/ppi/liv-com/fs218-transportation.pdf> Accessed December 2012.

Corcoran, Stephen B. "Senior Housing Trip Generation and Parking Demand Characteristics." Institute of Transportation Engineers 66th Annual Meeting. 1996.

Evansville Urban Transportation Study. *Trip Generation Report.* Evansville, IN. December 2001. <http://www.eutsmpo.com/reports/Trip%20Generation%20 2001.pdf> Accessed November 2012.

Flynn, Thomas E. and Andrew E. Boenau. "Trip Generation Characteristics of Age-Restricted Housing." *ITE Journal.* February 2007: Pages 30-32. Print.

Gumprecht, Blake. "The American College Town." Geographical Review, Vol. 93, No.1, pages 51-80. 2003.

Institute of Transportation Engineers. *Parking Generation.* 4th Edition. Washington D.C.: 2010. Print.

Institute of Transportation Engineers. *Trip Generation Manual*. 9th Edition. Washington D.C.: 2012. Print.

Institute of Transportation Engineers. *Trip Generation User's Guide.* 8th Edition. Washington D.C.: 2008. Print.

Jeihani, Mansoureh and Ricardo Camilo. "Do Retirement Housing Developments Make Fewer Trips than Regular Housing?" *ITE Journal*. June 2011: Pages 46-49. Print.

McCourt, Ransford S. *Parking Generation.* 3rd Edition. Washington D.C.: Institute of Transportation Engineers, 2004. Print

Navin, Francis P.D., Eanson Y.S. Ho, and Sany R. Zein. "Principles and Relationships of Parking and Trip Generation Rates." Institute of Transportation Engineers 65th Annual Meeting. 1995.

Racca, David P. "Active Adult (55+) Community Trip Generation Rates. Center for Applied Demography and Survey Research. University of Delaware. 2006.

San Diego State University. Draft EIR: Plaza Linda Verde. 2010. <http://newscenter.sdsu.edu/plazalindaverde/images/section_3_12_transportation_circulation_and_parking.pdf> Accessed November 2012.

Shoup, Donald C. "The Truth in Transportation Planning." University of California Transportation Center, UC Berkeley. Journal of Transportation and Statistics. Volume 6. 2002.

Southern New Hampshire Planning Commission, *Trip Generation Study*, July 2007. <http://www.snhpc.org/pdf/Trip%20Generation%20Report.pdf.> Accessed November 2012.

Spack, Mike. Technical Memorandum. Spack Consulting. April 12, 2012. <http://mikeontraffic.typepad.com/files/student-apartment-trip-generation-study-2.pdf>

Appendix

Table A.1: Morning and Evening Peak Hour Counts

		Vehicle Counts					
		Morning Peak Hour			Evening Peak Hour		
Apartment	**University**	**Entering**	**Exiting**	**Total**	**Entering**	**Exiting**	**Total**
Creekside	Auburn	71	108	179	191	220	411
Eagles West	Auburn	21	31	52	81	75	156
Edge	Auburn	14	31	45	69	61	130
Exchange	Auburn	30	93	123	131	113	244
Garden District	Auburn	28	31	59	119	109	228
Legacy	Auburn	29	44	73	76	94	170
Reserve	Auburn	34	42	76	73	98	171
Southern Edge	Auburn	14	26	40	23	32	55
The View	Auburn	2	12	14	28	27	55
Two 21	Auburn	15	33	48	73	127	200
University Heights	Auburn	27	85	112	105	99	204
University Village	Auburn	37	88	125	141	113	254
Veranda	Auburn	19	48	67	35	40	75
Heritage at Riverwood	Clemson	22	108	130	112	69	181
Heritage Point	Clemson	16	42	58	43	37	80
Lemans	Clemson	1	6	7	17	9	26
Pointe at Clemson	Clemson	10	55	65	71	51	122
Reserve	Clemson	16	107	123	102	71	173
Tiger Town Village	Clemson	8	62	70	55	47	102
University Village	Clemson	40	225	265	208	169	377
Bluffs	Alabama	n/a	n/a	n/a	59	68	127
Campus Way	Alabama	23	117	140	161	142	303
Canterbury	Alabama	6	11	17	15	18	33
Crimson Place	Alabama	11	50	61	84	63	147
Houndstooth	Alabama	10	37	47	62	47	109
Point O View	Alabama	6	41	47	60	44	104

Table A.2: Entering and Exiting Distributions

		Percent Distributions			
		Morning		Evening	
Apartment	**University**	**Entering**	**Exiting**	**Entering**	**Exiting**
Creekside	Auburn	39.66%	60.34%	46.47%	53.53%
Eagles West	Auburn	40.38%	59.62%	51.92%	48.08%
Edge	Auburn	31.11%	68.89%	53.08%	46.92%
Exchange	Auburn	24.39%	75.61%	53.69%	46.31%
Garden District	Auburn	47.46%	52.54%	52.19%	47.81%
Legacy	Auburn	39.73%	60.27%	44.71%	55.29%
Reserve	Auburn	44.74%	55.26%	42.69%	57.31%
Southern Edge	Auburn	35.00%	65.00%	41.82%	58.18%
The View	Auburn	14.29%	85.71%	50.91%	49.09%
Two 21	Auburn	31.25%	68.75%	36.50%	63.50%
University Heights	Auburn	24.11%	75.89%	51.47%	48.53%
University Village	Auburn	29.60%	70.40%	55.51%	44.49%
Veranda	Auburn	28.36%	71.64%	46.67%	53.33%
Heritage at Riverwood	Clemson	16.92%	83.08%	61.88%	38.12%
Heritage Point	Clemson	27.59%	72.41%	53.75%	46.25%
Lemans	Clemson	14.29%	85.71%	65.38%	34.62%
Pointe at Clemson	Clemson	15.38%	84.62%	58.20%	41.80%
Reserve	Clemson	13.01%	86.99%	58.96%	41.04%
Tiger Town Village	Clemson	11.43%	88.57%	53.92%	46.08%
University Village	Clemson	15.09%	84.91%	55.17%	44.83%
Bluffs	Alabama	n/a	n/a	46.46%	53.54%
Campus Way	Alabama	16.43%	83.57%	53.14%	46.86%
Canterbury	Alabama	35.29%	64.71%	45.45%	54.55%
Crimson Place	Alabama	18.03%	81.97%	57.14%	42.86%
Houndstooth	Alabama	21.28%	78.72%	56.88%	43.12%
Point O View	Alabama	12.77%	87.23%	57.69%	42.31%

Table A.3: Trip Generation Rates

			Morning		Evening	
Apartment	**University**	**Units**	**Peak Hour Trips**	**Rate (trips/unit)**	**Peak Hour Trips**	**Rate (trips/unit)**
Creekside	Auburn	374	179	0.48	411	1.10
Eagles West	Auburn	201	52	0.26	156	0.78
Edge	Auburn	116	45	0.39	130	1.12
Exchange	Auburn	312	123	0.39	244	0.78
Garden District	Auburn	205	59	0.29	228	1.11
Legacy	Auburn	172	73	0.42	170	0.99
Reserve	Auburn	180	76	0.42	171	0.95
Southern Edge	Auburn	40	40	1.00	55	1.38
The View	Auburn	36	14	0.39	55	1.53
Two 21	Auburn	156	48	0.31	200	1.28
University Heights	Auburn	246	112	0.46	204	0.83
University Village	Auburn	344	125	0.36	254	0.74
Veranda	Auburn	96	67	0.70	75	0.78
Heritage at Riverwood	Clemson	304	130	0.43	181	0.60
Heritage Point	Clemson	176	58	0.33	80	0.45
Lemans	Clemson	51	7	0.14	26	0.51
Pointe at Clemson	Clemson	96	65	0.68	122	1.27
Reserve	Clemson	177	123	0.69	173	0.98
Tiger Town Village	Clemson	94	70	0.74	102	1.09
University Village	Clemson	311	265	0.85	377	1.21
Bluffs	Alabama	140	n/a	n/a	127	0.91
Campus Way	Alabama	192	140	0.73	303	1.58
Canterbury	Alabama	80	17	0.21	33	0.41
Crimson Place	Alabama	148	61	0.41	144	0.97
Houndstooth	Alabama	130	47	0.36	109	0.84
Point O View	Alabama	138	47	0.34	104	0.75

A.4: Peak Hours

		Peak Hours	
Apartment	**University**	**Morning**	**Evening**
Creekside	Auburn	8:00-9:00	4:45-5:45
Eagles West	Auburn	7:15-8:15	4:00-5:00
Edge	Auburn	7:45-8:45	4:45-5:45
Exchange	Auburn	7:00-8:00	5:00-6:00
Garden District	Auburn	7:00-8:00	4:45-5:45
Legacy	Auburn	7:45-8:45	4:15-5:15
Reserve	Auburn	7:45-8:45	4:30-5:30
Southern Edge	Auburn	7:00-8:00	4:00-5:00
The View	Auburn	7:00-8:00	4:15-5:15
Two 21	Auburn	7:15-8:15	4:45-5:45
University Heights	Auburn	7:15-8:15	5:00-6:00
University Village	Auburn	7:45-8:45	5:00-6:00
Veranda	Auburn	7:15-8:15	4:15-5:15
Heritage at Riverwood	Clemson	7:15-8:15	4:45-5:45
Heritage Point	Clemson	7:30-8:30	4:30-5:30
Lemans	Clemson	7:30-8:30	5:00-6:00
Pointe at Clemson	Clemson	8:00-9:00	4:45-5:45
Reserve	Clemson	7:45-8:45	5:00-6:00
Tiger Town Village	Clemson	7:00-8:00	4:30-5:30
University Village	Clemson	7:00-8:00	5:00-6:00
Bluffs	Alabama	n/a	4:00-5:00
Campus Way	Alabama	7:15-8:15	5:00-6:00
Canterbury	Alabama	8:00-9:00	4:45-5:45
Crimson Place	Alabama	8:00-9:00	4:45-5:45
Houndstooth	Alabama	7:30-8:30	4:45-5:45
Point O View	Alabama	7:00-8:00	4:30-5:30