Travel Patterns of University Students in North Carolina

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Abstract

University students have unique travel patterns compared to the general population. This research project uses the university student travel survey data collected from six university campuses in North Carolina to conduct travel behavior analyses and develop travel demand models for university students. The travel pattern analyses help us understand how university students make their daily trips. The university student models developed can be incorporated into the current regional travel demand models in North Carolina to improve the models built for trips made by university students.

The major findings of the travel pattern analyses are as follows. The average daily trip rate of university students in the six campuses surveyed is 5.34 trips/day. Whether a university student is living on campus is a significant and the most important factor for the differences in trip rate. On-campus students make more trips than off-campus students but most of them are within the campus. The average trip distance is 3.55 miles and the average travel time is 12.44 minutes. Most of the universities follow the similar time-of-day patterns. Trips start increasing at 7 am and the AM peak falls between 9 am to 10 am. The peak hours of the whole day are identified between 12pm and 2 pm. The PM peak may occur either between 3 pm and 4 pm or between 5 pm and 6 pm. On-campus students choose to walk most while more than half of the off-campus students' trips are done by auto vehicles. More than half of the trips generated by students who have parking permits are made by driving alone. University students without parking permits are most likely to walk.

Keywords: *travel behavior, travel demand model, university student, North Carolina*

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Literatures on university students' trip making patterns show that university students are more active than the general population. The travel behaviors of students living on campus are different from those living off campus. University students are more likely to choose walking and biking than the general population.

As for the status of modeling university student trips in the regional travel demand models in North Carolina, university student trips are better represented in the models of larger Metropolitan Planning Organizations than the smaller ones. However, lack of observation data still limits the development of separate models for university students.

Travel Pattern Analysis

Trip Rate

The average daily trip rate of university students in the six campuses surveyed is 5.34 trips/day. On-campus students generate more trips than off-campus students. Full-time students have higher overall trip rates than part-time students. Undergraduate students generally make more trips than graduate students. Unemployed students usually have higher trip rates than employed students. Students without cars generate more trips than those that have cars.

On-campus students make more within trips, but fewer crossing and outside trips than off-campus. Full-time students generate more within and crossing trips, but fewer outside trips than part-time students. Graduate students have fewer within trips, but more outside trips than undergraduate students. Employed students have lower within trip rates, but higher crossing and outside trip rates than unemployed students. Students with cars make fewer within trips, but more crossing and outside trips than those without cars. Students with parking permits have fewer within trips, but more crossing trips than students without parking permits.

Most of the within trips are generated from one classroom to another, between on-campus homes and classrooms, as well as between classrooms and dining halls. The off-campus ends of the crossing trips are most likely to be either off-campus homes or places for dining, shopping, recreation, and social activities. The outside trips are primarily made among off-campus homes, dining or shopping places and places for recreation or social activities.

Whether a university student is living on campus or off campus is a significant and the most important factor that contributes to the differences in the trip rates. Full time status is also a significant factor across all the trip classifications but has a smaller impact on the trip rates.

Trip Distance and Travel Time

The average trip distance of trips made by university students in all of the six campuses surveyed is 3.55 miles and the average travel time is 12.44 minutes. Off-campus students make longer trips than off-campus students in trip distance and travel time. Full-time students generate trips that are shorter in distance and time than part-time students. Graduate students travel longer than undergraduate students in terms of both distance and travel time. Students who are employed are more likely to make trips that have longer distances and travel time. Students with cars make trips that are longer in distance and travel time than those without cars. Students that have parking permits travel farther and longer than students with no parking permits.

Within trips are shorter in terms of both trip distance and travel time than the other trips. Crossing trips are shorter than outside trips in distance, but longer in travel time. In terms of the average trip distance, drive alone trips are longer than the other trips. Carpool trips are the second longest and transit trips are in the third place. Bike trips are longer than walk trips. As per the average travel time, public transit trips take longer time than the other trips, followed by drive alone trips, shared ride trips, bike trips and walk trips in order. For the average speed, single-occupancy vehicle trips travel fastest. Shared ride trips are slower than the drive alone trips, but still faster than the other trips. Public transit trips are of higher speeds than walk trips, but not significantly faster than bike trips. Bike trips are significantly faster than walk trips.

Time of Day

Most of the universities follow the similar time-of-day patterns. Trips start increasing at 7 am and the AM peak falls between 9 am to 10 am. The peak hours of the whole day are identified between 12pm and 2 pm. The PM peak may occur either between 3 pm and 4 pm or between 5 pm and 6 pm.

Trips generated by on-campus students are slightly more concentrated between 9 am and 2 pm. On the other hand, trips made by off-campus students are distributed more evenly from 8 am to 6 pm. Within trips are concentrated during the school time between 9 am and 2 pm. Crossing trips are more evenly distributed from 8 am to 6 pm. Outside trips have two obvious peak periods, a lower peak in the morning from 7 am to 10 am and a higher peak in the late afternoon and evening from 4 pm to 9 pm.

Trips for attending classes peak in the morning from 8 am to 11 am and decrease continually. Home trips are constant after 12 pm till 10 pm. Work trips peak from 7 am to 9 am and stay constant between 9 am and 6 pm. Trips for dining or shopping have two identical peaks, a midday peak from 11 am to 1 pm and a PM peak from 5 pm to 8 pm. Trips for recreation or social activities are more likely to occur from 5 pm to 8 pm.

Single-occupancy vehicle trips stay constant from 7 am to 5 pm, peak between 5 pm and 6 pm, and start to decrease after 6 pm. Shared ride trips increase continually until reaching the PM peak at around 6 pm to 8 pm. Public transit trips peak between 8 am to 9 am and begin to decrease after that. Bicycle trips increase from 7 am, peak between 10 am and 11 am, and decrease afterwards. Walk trips are concentrated between 9 am and 2 pm.

Mode Choice

University students are more likely to choose alternative transportation modes to automobiles. On-campus students choose to walk most while more than half of the off-campus students' trips are done by auto vehicles. Full-time students are in favor of both driving and walking while part-time students like driving alone. Graduate students drive more while undergraduate students prefer walking more than driving alone. Employed students would like to drive while students who are not employed prefer walking more. Students with cars drive more while those who do not have cars choose walking most. More than half of the trips generated by students who have parking permits are made by driving alone. University students without parking permits are most likely to walk.

Within trips tend to be made by walking most. Crossing trips generated by on-campus students are most likely to be made through carpooling. Off-campus students prefer driving alone for crossing trips. Outside trips are dominated by automobiles. On-campus students are in favor of carpooling while off-campus students like driving alone more.

Walking is the main mode for trips that are within 3 miles, but the mode share decreases sharply in longer trips. With the increase in the trip distance, the mode share of single-occupancy driving increases correspondingly and it dominates the trips that are longer than 3 miles. Shared ride trips stay at about 20% of mode share for trips that are 3 miles or more in distance. The public transit percentage peaks when the trip distance ranges from 3 to 6 miles.

Travel Demand Model

Based upon the travel pattern analyses, university student travel demand models are developed which can fit into the current regional models in the areas with universities and colleges in North Carolina. Conventional four-step travel demand model is adopted as the foundation for the university student travel demand model developed in this project. Five trip categories are defined and modeled, including within trips, on-campus student crossing trips, off-campus student university-based home crossing trips, off-campus student university-based non-home crossing trips and outside trips.

The model development mainly focuses on the first three steps of the four-step model, which are trip generation, trip distribution and modal split. Cross-classification models are developed for trip generation models. Trip distribution models are based on Gravity Model with Gamma Functions for the friction factors. Time of day and directional split models are built before mode choice models to better model the travel flows based on the time periods. Modal split models first separate non-motorized trips and motorized trips through Inverse Power Functions, and then split automobile trips and public transit trips through linear regression models. Vehicle occupancy rates based on the time of day are developed to convert the university student auto person trips into auto vehicle trips that can be assigned to road networks.

1. Introduction

University students have been recognized as a unique and important component of the population that has a significant impact on the transportation network, especially the vicinity of the university campuses. Owing to the lack of observed information on the travel behaviors of university students, their trip making patterns are neither well understood nor well represented in travel demand models. University students are usually treated in the same manner as the general population and assumed to have similar travel behaviors to one-person households with low income. However, as a young and busy group, university students can have very different travel patterns than the rest of the population. They might have more mandatory trips to various classes, and more recreation trips due to the better access to many university facilities. The trip distances, mode choices, and time distributions of university students' trips may also vary from the characteristics of one-person low-income households' trips. Thus, it is important to separate university students from the general population and treat them differently in travel demand models.

North Carolina has an extensive system of more than 150 public and private universities and colleges with more than 475,000 students attending them across the entire state (City Town Info, 2015). However, very few surveys have been conducted to study the travel behaviors of university students in North Carolina, leaving a dearth of information and also an opportunity to fill the gap.

This research project will first use the university student travel survey data to develop a detailed analysis of university students' trip making patterns. Descriptive cross-classification analyses and regression models will be used to analyze the university characteristics, trip rates, trip distances, travel time, mode choices and time of day. The analyses will give us a better understanding of the travel behaviors of university students in North Carolina and can also be used as a ground for the following part of the research. The second part is to use the observed travel survey data to develop travel demand models for university students in North Carolina, which can be used for regions that have universities or colleges. The university student travel demand model will be developed based on the conventional four-step travel demand model and will be incorporated into the current regional models.

2. Literature Review

The literature review for this research project will focus on two parts. The first part will summarize the previous surveys and studies conducted on the travel behaviors of university students. The second part will review the current practices of modeling university student trips in the local travel demand models in North Carolina.

2.1. Previous Student Surveys and Studies

In North Carolina, a student activity travel survey was conducted for North Carolina State University (NCSU) in 2001 by using a travel diary for one school day. 843 students were surveyed and the results showed that undergraduate students and on-campus residents were engaged in more activities than graduate students and off-campus students. Walking was the primary mode for on-campus students while automobile was the major mode for off-campus residents. The student trip rates were higher than the regional average trip rates recorded in the Triangle Regional Model household travel survey (Eom, Stone, & Ghosh, 2009). The survey data was also used to develop a transitional methodology to incorporate the activity-based university student data into a conventional travel demand model (Eom, 2007). Besides the travel survey at NCSU, Rodriguez and Joo (2004) used data for student and staff commuters to the University of North Carolina in Chapel Hill to examine the relationship between travel mode choices and attributes of the local physical environment.

Across the United States, the most recent significant survey on the travel behaviors of university students at the state level was conducted by Virginia Department of Transportation (VDOT) in 2009 at four Virginia public universities: Old Dominion University (ODU), Virginia Commonwealth University (VCU), University of Virginia (UVA) and Virginia Tech (VT). The study collected data on travel behaviors, socio-demographics, and context variables of 2,784 university students. The results indicated that the travel behaviors of university students were different from those of the general population. Differences were also found between students living on campus and off campus as well as between students attending urban campuses and suburban campuses (Khattak, Wang, Son, & Agnello, 2011). In 2010, another set of surveys were conducted for ODU and VT with refined survey instrument. A study based on the survey data of 1,468 ODU students was developed and showed that students living on campus or near campus are significantly more likely to walk or bike and less likely to drive. The behavioral models provided helpful information that could be used to better represent the university students in regional travel demand models and to improve strategic planning (Wang, Khattak, & Son, 2012).

The Ohio State University conducted a web-based campus transportation survey in 2011 to understand the travel patterns of the campus community and to inform recommendations to reduce single-occupancy vehicle travel. Discrete choice models were estimated to analyze commuter mode choices to travel to campus (Akar, Flynn, & Namgung, 2012). A study on the gender differences in travel behavior with a focus on bicycling was also conducted at the Ohio State University (Akar, Fischerb, & Namgung, 2013).

The Arizona State University Travel Demand Survey was conducted in the spring of 2007 to collect travel data from 2,036 students, and 1,812 faculty and staff. The survey obtained detailed household and personal socio-economic and demographic characteristics, class and work schedules for a typical week, characteristics of traveling to and from the campus, a travel log for all trips to and from the campus made on the most recent day that the individual traveled to campus, and also a stated preference component to evaluate light rail project. The rate of student trips to and from campus was 2.50 trips/day. A trip generation model and a multinomial logit mode choice model were developed based on the survey to study the feasibility of the proposed light rail project (Pendyala, 2007).

The Indiana University Student Trip Survey was conducted in May of 1998 on the Bloomington campus. 583 usable surveys were completed and 3.9 daily inter-zonal trips per person were recorded (City of Bloomington MPO). The motorized Origin-Destination (O-D) Matrix for university student trips derived from the survey was used in the Bloomington metropolitan travel demand model (City of Bloomington/Monroe County MPO).

There are also some international studies on the travel behaviors of university students. In Europe, Kamruzzaman et al. (2011) used a two-day travel and activity diary method to investigate the trips and activities of college students in Northern Ireland. The diary included the number of unique locations visited, the average daily distance traveled, and the average daily activity duration. Ubillos and Sainz (2004) used 1,780 surveys filled in by students who traveled to university and resided in areas surrounding the city of Bilbao, Spain, to estimate the potential effects of changing the supply of public transport to draw new collective transport users away from private vehicles.

In Australia, Shannon et al. (2006) surveyed 1,040 students and 1,170 staff at the University of Western Australia and examined commuting patterns, potential for changes, and barriers and motivators affecting transport decisions. In Asia, Joewono et al. (2013) explored university students' characteristics of activities and travel needs based on two-day travel diaries of 400 students in 10 universities in the city of Bandung, Indonesia. Limanond et al. (2011) examined travel patterns of 130 students who studied and lived on campus in a rural university in Thailand based on the participants' travel diaries for seven consecutive days in a typical school week.

2.2. Status of Modeling University Student Trips in North Carolina

In 2012, among all 17 Metropolitan Planning Organizations (MPOs) in North Carolina, at least four MPOs, including the French Broad River MPO, the Greater Hickory MPO, the Jacksonville MPO and the Rocky Mount MPO, did not collect specific data or model travel demand related to university student travel, since they did not recognize university student populations as being large enough to significantly impact their local transportation networks.

The Metrolina Regional Travel Demand Model includes the Cabarrus-Rowan MPO, the Gaston Urban Area MPO and the Mecklenburg-Union MPO. Home-based university (HBU) was modeled in the Metrolina model. HBU trips referred to any direct trips between homes and colleges/universities, including vocational/technical schools and other professional education.

The trip production model for HBU was a cross-classification model, in which stratified trip rates were multiplied by the number of households in each zone by household stratification to calculate trip productions. The trip attraction model for HBU trips was a linear regression model. The trip distribution model for HBU was a Gravity Model and the mode choice model was a nested logit model (Allen, 2006).

The Triangle Regional Model (TRM) includes the Capital Area MPO and the Durham-Chapel Hill-Carrboro MPO. During the development of TRM, a university student model was developed to better represent on-campus and off-campus students' travel behaviors in the travel demand model. The 2001 NCSU Student Survey data was used to help incorporate on-campus students into the household strata one (zero car) or strata two (low income with car), and then model them in the same way as regular households. For the off-campus students, no special treatment was applied and they were modeled as the general population (Triangle Regionl Model Service Bureau, 2011).

The Piedmont Triad Regional Model (PTRM) includes the Greensboro MPO, the Winston-Salem MPO, the High Point MPO and the Burlington-Graham MPO. In 2008, the PTRM enhanced the university student model by replacing the previous distribution model with a fixed relative distribution for four campuses, including Greensboro College, High Point University, Salem College and University of North Carolina - Greensboro. The remaining campuses in the area continued to use the previous home-based university distribution model (Parsons Brinkerhoff, 2008).

In the Wilmington MPO travel demand model, university campuses were treated as special generators. Using ITE rates and independent data from a number of university campus transportation studies, a reasonable trip generation target was established for the university campus zones. No special treatment was applied to university students in the model steps of trip distribution and mode choice (Martin Alexiou Bryson, 2007).

Greenville model introduced Home-Based School/University (HBSU) to model the university student trips. However, this trip purpose also included home-based school (K-12) trips. In the trip production model for HBSU, the number of HBSU trips was a linear function of the number of university students living in group quarters and the number of households with K-12 and university students. Trip attraction rates were used in the trip attraction model for HBSU and the rates were developed from available traffic counts and socio-economic data, the ITE Trip Generation Manual, and other studies. Gravity models were used to distribute the HBSU trips. In the mode choice step, these trips were factored to eliminate the non-motorized, transit, and auto passenger trips, leaving only the auto vehicle trips (Kimley-Horn and Associates, 2006).

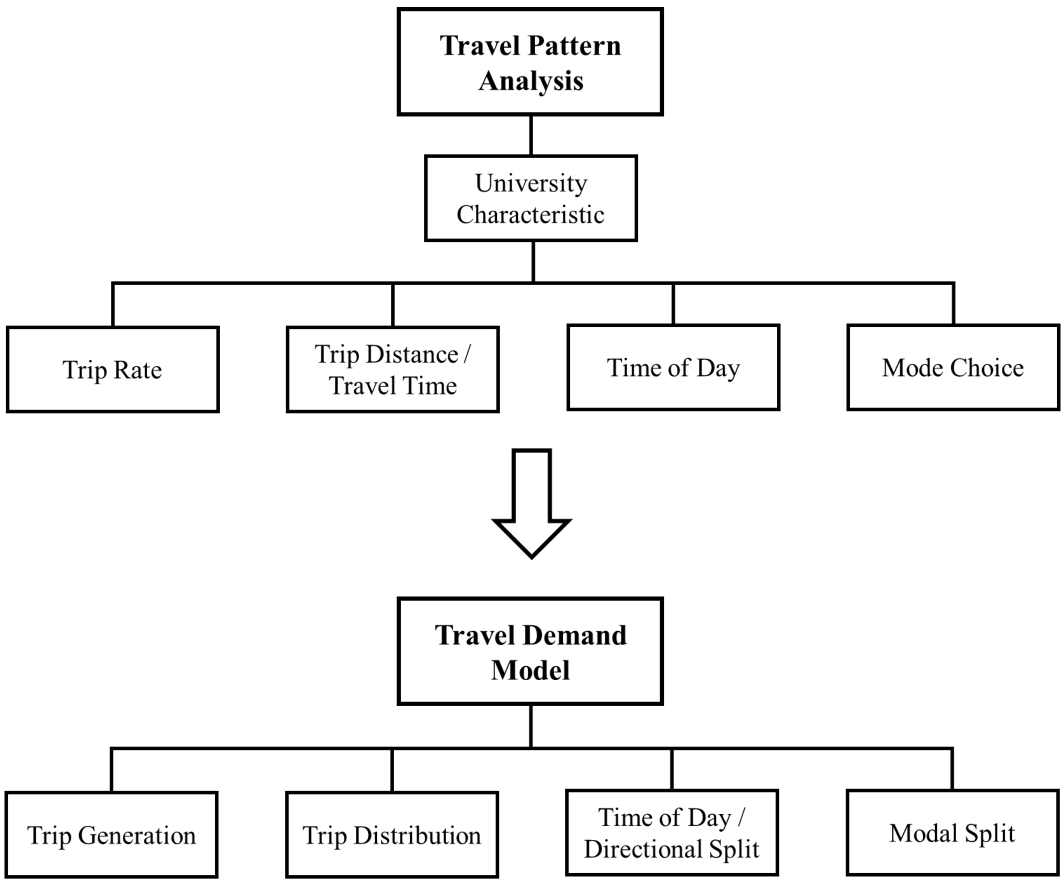
Through the literature review, we can find that university students are more active than the general population. The travel behaviors of students living on campus are different from those living off campus. University students are more likely to choose walking and biking than the general population. University student trips are better represented in the regional travel demand models of larger MPOs. However, lack of observation data still limits the development of separate models for university students.

3. Methodology

In this section, we will first discuss the conceptual structure of the research to analyze and model the university student trips. The second part will show the details of the travel survey data collected that the research project is based on. The third part will categorize the university student trips as a base for the travel pattern analysis as well as the travel demand model development.

3.1. Conceptual Structure

Figure 3.1 Conceptual Structure



The research mainly consists of two parts as shown in Figure 3.1. The first section will present a travel behavior analysis for university students in North Carolina based on the travel survey data. University characteristics, trip rates, trip distances and travel time, time of day, and mode choices of university student trips will be analyzed in detail. University characteristics, including both the campus settings and the student characteristics of the surveyed universities, will be discussed. For trip rates, descriptive cross-classification analysis will be used to examine the trip rates by university, student characteristic, trip classification, trip type and purpose. Linear regression models will also be built to identify the significant and important student characteristics that contribute to the differences in trip rates. Trip distances and travel time by university, student characteristic, trip type and mode choice will also be analyzed. Charts will be developed to illustrate the time of day by university, residential status, trip classification, purpose and mode choice. Additionally, mode choices by university, student character, trip type and trip distance will be investigated.

Based upon the travel pattern analysis, the second section will try to find out how to use the survey data to develop university student travel demand models that can fit into the current regional models in the areas with universities and colleges. The model development will mainly focus on the first three steps of the conventional four-step travel demand model, which are trip generation, trip distribution and modal split. Cross-classification models will be developed for the trip generation models. The trip distribution models will use Gravity Models with Gamma Functions for the friction factors. Time of day and directional split models will be built before mode choice models to better model the travel flows based on the time periods. Modal split models will first separate non-motorized trips and motorized trips, and then split automobile trips and public transit trips. Vehicle occupancy rates based on the time of day will be used to convert the auto person trips into auto vehicle trips that can be assigned to road networks.

3.2. Travel Survey Data

From March 2013 to May 2014, an extensive university student online travel survey, sponsored by the North Carolina Department of Transportation (NCDOT), was conducted by the Institute for Transportation Research & Education at NCSU (ITRE) with the support of surveyed universities. Six universities with different characteristics were selected to be surveyed, including North Carolina State University (NCSU), University of North Carolina at Greensboro (UNCG), Appalachian State University (ASU), Fayetteville State University (FSU), University of North Carolina at Wilmington (UNCW) and University of North Carolina at Charlotte (UNCC). 7,408 students started the survey and 3,397 of them were retained as valid samples with 17,427 trip records. Detailed personal and trip information were collected. The surveyed university names, time of the surveys, and sample sizes of persons and trips are all listed in Table 3.1. The survey data has been carefully cleaned and checked to guarantee the quality of the data so that each person and trip record makes sense and consistent. The survey data are reorganized into Person Table, Place Table and Trip Table as shown in Table 3.2, Table 3.3 and Table 3.4.

Table 3.1 Survey Sample Sizes

University Name	Time of Survey	Number of Person Samples	Number of Trip Samples
NCSU	March-April 2013	336	1,978
UNCG	April-May 2013	383	2,022
ASU	March-April 2014	266	1,520
FSU	February-April 2014	224	1,074
UNCW	February-April 2014	838	4,585
UNCC	February-May 2014	1,350	6,248
Total		3,397	17,427

Table 3.2 Major Fields in Person Table

Person_ID	Person sample ID (a unique identifier that can links the Person, Place and Trip Table)
Education Status	Whether the respondent is a graduate student based on "Class_status" (0 = Undergraduate; 1 = Graduate)
Enrollment Status	Whether the respondent is a full-time student based on "Class_status" and "Credit_hours" (0 = Part-Time; 1 = Full-Time). A student is considered as a full time student if he/she is an undergraduate and takes >= 12 credit hours or a graduate and takes >=9 credit hours.
Residential Status	Whether the respondent lives on campus (0 = Off-Campus; 1 = On-Campus)
Employment	Whether the respondent is employed (0 = No; 1 = Yes)
Auto_Ownership	Whether the respondent has a car to use (0 = No; 1 = Yes)
Parking_Permit	Whether the respondent has a parking permit (0 = No; 1 = Yes)
Home_Campus_Dist	Shortest straight line distance (in miles) from the respondent's home to any university campus boundaries (off-campus students only)
Weight	Person weight for the final remaining person records based on residence locations (on-campus vs. off-campus), credit hours (full-time vs. part-time) and class status (undergraduate vs. graduate)

Table 3.3 Major Fields in Place Table

Person_ID	Person sample ID (a unique identifier that can links the Person, Place and Trip Table)
Place_ID	Place ID in the format of Person_ID followed by three digits for the order of the place visited
Place_Type	Place types which include home, campus, off-campus workplace and other
Place_Lat	Latitude of the place
Place_Long	Longitude of the place
TAZ	TAZ ID of the place based on the local model

Table 3.4 Major Fields in Trip Table

Person_ID	Person sample ID (a unique identifier that can links the Person, Place and Trip Table)
Start_PlaceID	Place ID of the start place
End_PlaceID	Place ID of the end place
Time_Leave_StartPlace	Time when the respondent left the start place
Trip_Duration	Estimate of the trip duration by the respondent from the start place to the end place
Time_Period	Time period of the trip based on the middle time of the trip. AM = Morning Peak; MD = Midday; PM = Afternoon Peak; OP = Off-peak. The definition of the time period is based on the local model.

Purpose	The main purpose for traveling to each of the places. The possible values are go home, attend classes/study/research, work, dining/shopping, recreational/social/community service/personal, and other.
Mode_1	Major transportation mode used to complete the trip. The possible values are drive alone (auto/van/truck), car pool (either as driver or as passenger-auto/van/truck), public bus/private shuttle, motorcycle/motorized moped or scooter, bicycle, walk, and other.
Mode_2	Secondary transportation mode used to complete the trip. A respondent might use more than one mode in a trip.
Mode_3	Other transportation mode used to complete the trip. A respondent might use more than one mode in a trip.
Total_Travelers	The total number of people traveling together for the car pool mode including the respondent
Network_Dist	Highway network distance between the start place and the end place, based on the highway network and the traffic assignment results from the local model. It is determined by the TAZ ID of Start_PlaceID, the TAZ ID of End_PlaceID, and Time_Period.
Network_time	Auto travel time between the start place and the end place, based on the highway network and the traffic assignment results from the local model. It is determined by the TAZ ID of Start_PlaceID, the TAZ ID of End_PlaceID, and Time_Period.
Weight	Trip weight, which is equal to the person weight from the person table based on the person ID.

3.3. Trip Categorization

Based on the residential statuses, trip purposes, start places and end places of the trips, we can categorize the university student trips into ten trip types which cover all the trips made by university students as shown in Figure 3.2. Boxes with blue borders are places on campus while black outlined boxes are off-campus places. Student trips are grouped based on the students' residential location. On-campus student trips are illustrated as blue dashed arrows while off-campus student trips are represented by solid black arrows.

Figure 3.2 Trip Categorization

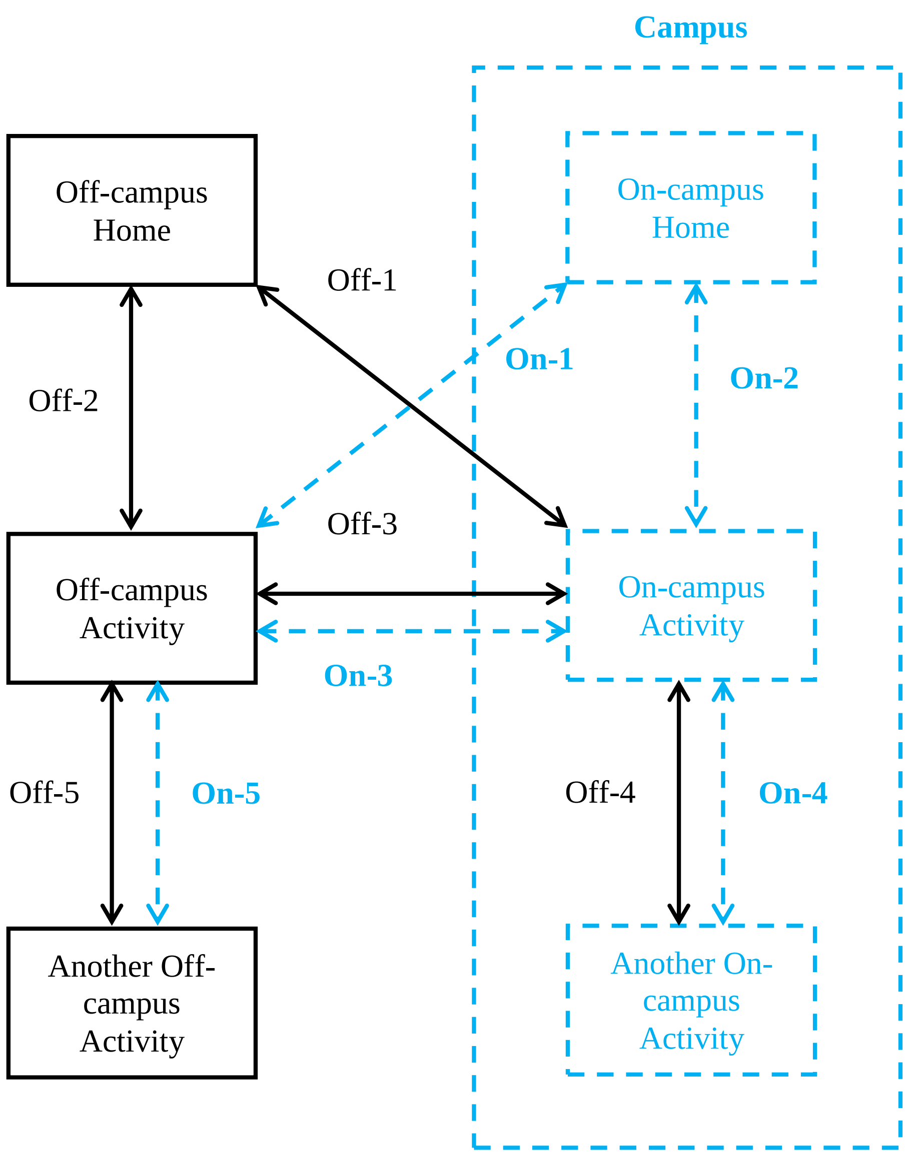


Table 3.5, Table 3.6 and Table 3.7 show the details of each trip type. On-campus student and off-campus student have five trip types respectively according to the start and end places shown in Table 3.5. Each trip type can also be categorized into University-Based Home trip (UBH),

University-Based Non-Home trip (UBNH), Home-Based Non-University trip (HBNU), and Non-Home Non-University trip (NHNU) based on the trip purposes (see Table 3.6). Table 3.7 shows that the trip types can also be classified as crossing the university boundary trip (crossing trip), within the university trip (within trip), and outside of the university trip (outside trip).

Table 3.5 Trip Types

Student Type	Trip Type	Description	Characteristic
On-Campus Student	On-1	Between home and non-university	Crossing the university boundary
	On-2	Between home and university	Within the university
	On-3	Between university and non-university	Crossing the university boundary
	On-4	Within university	Within the university
	On-5	No trip end is home or university	Outside of the university
Off-Campus Student	Off-1	Between home and university	Crossing the university boundary
	Off-2	Between home and non-university	Outside of the university
	Off-3	Between university and non-university	Crossing the university boundary
	Off-4	Within university	Within the university
	Off-5	No trip end is home or university	Outside of the university

Table 3.6 Trip Purposes

Trip Purpose	On-Campus Student	Off-Campus Student
UBH (University-Based Home)	On-2	Off-1
UBNH (University-Based Non-home)	On-3, On-4	Off-3, Off-4
HBNU (Home-Based Non-University)	On-1	Off-2
NHNU (Non-Home Non-University)	On-5	Off-5

Table 3.7 Trip Classifications

Trip Classification	On-Campus Student	Off-Campus Student
Crossing the university boundary	On-1, On-3	Off-1, Off-3
Within the university	On-2, On-4	Off-4
Outside of the university	On-5	Off-2, Off-5

4. Travel Pattern Analysis

In this section, we will first look at what are the unique characteristics that each of the six surveyed universities have. Secondly, we will explore how the trip rates, trip distances, travel time, time of day and mode choices of university student trips vary among different trip types, university campuses and student characteristics. The detailed travel pattern analyses will provide a solid foundation for the following development of travel demand models for university students in North Carolina.

4.1. University Characteristics

The six universities surveyed differ from each other in terms of not only the campus characteristics but also the student demographics. The information can be useful for the planners or modelers to identify the universities that have the most similar settings to their own universities when applying the university student travel demand models.

4.1.1. Campus Characteristics

Table 4.1 University Campus Characteristics

Campus Characteristic	NCSU	UNCG	ASU	FSU	UNCW	UNCC
City/Town	Raleigh	Greensboro	Boone	Fayetteville	Wilmington	Charlotte
Model Area (Square Mile)[1]	3,379 (Large)	1,940 (Medium)	93 (Small)	1,406 (Medium)	814 (Medium)	4,600 (Large)
Population (2013) [2]	431,746 (Large)	279,651 (Medium)	18,211 (Small)	204,408 (Medium)	112,067 (Medium)	792,862 (Large)
Student Enrollment (2013 Fall) [3]	34,009 (Large)	17,707 (Medium)	17,838 (Medium)	6,179 (Small)	12,209 (Medium)	26,571 (Large)
University Student Percentage of Population	8% (Medium)	6% (Small)	98% (Large)	3% (Small)	11% (Medium)	3% (Small)
Campus Size (Acre) [3]	2,090 (Large)	231 (Small)	1,732 (Large)	92 (Small)	661 (Medium)	1,000 (Medium)
Campus Setting	Urban	Urban	College Town	Urban	Suburban	Suburban
Public Transit[4]	20 (Large)	10 (Medium)	-	-	9 (Medium)	7 (Small)

[1] Source: Local travel demand models
[2] Source: US Census Bureau
[3] Source: University official websites
[4] Source: Local travel demand models; the number of transit routes that have bus stops within 1 mile from the campus boundary; transit networks for ASU and FSU not available

Table 4.1 lists the detailed information on the campus characteristics of each university. NCSU has a large campus size and a large number of students in the urban area of a large city with excellent public transit services. UNCG is a medium university as per the student enrollment with a relatively small campus in the urban area of a medium size city. ASU has a medium size of university students in a large campus located in a small college town. FSU is a rather small university in terms of both student enrollment and campus size in the urban area of a medium city. UNCW is a medium size university in the suburban area of a medium city, which is about 4.5 miles from the Downtown Wilmington. UNCC has a large number of students in a medium-sized campus located in the suburb of a large city which is about 8 miles from the Charlotte CBD.

4.1.2. Student Characteristics

Table 4.2 University Student Characteristics

Student Characteristic	NCSU	UNCG	ASU	FSU	UNCW	UNCC	All
On-Campus	29%	25%	35%	29%	34%	20%	28%
Off-Campus	71%	75%	65%	71%	66%	80%	72%
Full-Time	85%	77%	96%	70%	86%	77%	83%
Part-Time	15%	23%	4%	30%	14%	23%	17%
Graduate	24%	20%	6%	12%	10%	19%	17%
Undergraduate	76%	80%	94%	88%	90%	81%	83%
Employed	56%	58%	53%	56%	59%	65%	59%
Non-Employed	44%	42%	47%	44%	41%	35%	41%
Car	74%	80%	74%	77%	87%	89%	80%
No Car	26%	20%	26%	23%	13%	11%	20%
Parking Permit	40%	35%	25%	60%	65%	65%	47%
No Parking Permit	60%	65%	75%	40%	35%	35%	53%

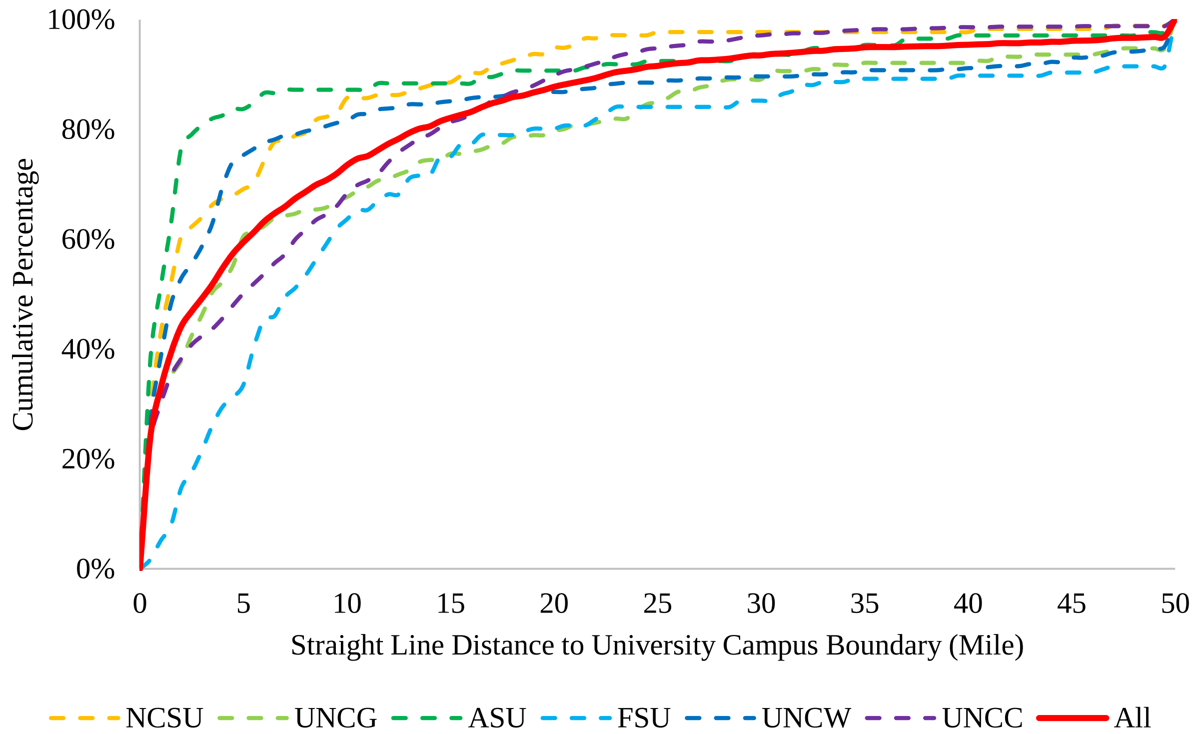
Table 4.2 shows how the student demographics vary among the six universities. ASU and UNCW have the highest on-campus student percentages while 80% of UNCC students live outside of the campus. 96% of ASU students are full time while 30% of FSU students are registered as part-time students. Almost one-fourth of the NCSU students are in the graduate school while 94% of ASU students are undergraduate students. UNCC has the highest percentage of employed students while ASU has only 53%. 26% of NCSU and ASU students do not have cars while 89% of UNCC students are car owners. Only 35% of UNCW and UNCC students have parking permits while only 25% of ASU students do not have a parking permit.

Table 4.3 Weighted Off-Campus Home Distances to University Campuses

Straight Line Distance to Campus Boundary	NCSU	UNCG	ASU	FSU	UNCW	UNCC	All
Within 1 Mile	41%	32%	32%	4%	40%	29%	33%
Within 2 Miles	60%	37%	70%	14%	54%	37%	46%
Within 5 Miles	70%	59%	86%	31%	75%	49%	59%
Within 10 Miles	88%	67%	89%	60%	81%	67%	71%
Within 20 Miles	96%	80%	91%	78%	87%	89%	82%

Table 4.3 and Figure 4.1 illustrate how the homes of off-campus students disperse around the university campus boundaries. Off-campus students in FSU tend to live further away from the campus because it has a rather small campus in a medium size city. ASU off-campus students live closer to the campus boundary because of the large campus size as well as the small size of the college town.

Figure 4.1 Off-Campus Home Distances to University Campuses



The off-campus home analysis can be used to understand where the off-campus students live in terms of the distances to the campus boundaries. The information can help develop models to identify the number of off-campus students in each Traffic Analysis Zone (TAZ) near the university campuses so that we can tease out the university students from the general population to avoid double counting when adding the university student models to the general travel demand models. However, a more detailed look at the land uses in each TAZ is highly recommended when developing the off-campus home models.

4.2. Trip Rate

In order to understand how the daily trip rates of university students differ based on the university campuses, student characteristics and trip purposes, we can develop cross-classification analyses as well as linear regression analyses to have a deep insight of the critical factors that contribute to the differences in trip rates.

4.2.1. Cross-Classification Analysis

Table 4.4 Weighted Overall Trip Rates by University Campus and Student Characteristic

Student Characteristic	NCSU	UNCG	ASU	FSU	UNCW	UNCC	All
On-Campus	7.07	6.18	6.56	4.51	6.01	4.99	6.17
Off-Campus	5.28	4.95	5.31	4.80	5.28	4.62	5.02
Full-Time	6.01	5.57	5.80	4.90	5.65	4.80	5.53
Part-Time	4.63	4.22	4.52	4.29	4.83	4.37	4.44
Graduate	4.76	4.68	5.37	4.37	4.46	4.24	4.60
Undergraduate	6.13	5.40	5.77	4.76	5.65	4.81	5.49
Employed	5.63	5.19	5.74	4.43	5.47	4.81	5.27
Unemployed	6.03	5.35	5.75	5.07	5.62	4.48	5.45
Car	5.52	5.01	5.39	4.79	5.40	4.66	5.13
No Car	6.61	6.28	6.77	4.46	6.40	5.03	6.21
Parking Permit	5.55	5.51	5.43	5.05	5.45	4.57	5.15
No Parking Permit	5.97	5.12	5.85	4.22	5.68	4.93	5.51
Total	5.80	5.26	5.74	4.72	5.53	4.70	5.34

Table 4.4 shows the details of how overall trip rates vary among different universities and student characteristics. UNCC and FSU have significantly lower overall trip rates than the other universities. On-campus students generate significantly more trips than off-campus students except FSU where off-campus students travel more frequently but not significantly. Full-time students have significantly higher overall trip rates than part-time students except ASU and FSU where the differences are not significant mainly due to the small sample sizes. Undergraduate students generally make more trips than graduate students except UNCG, ASU and FSU where the differences are not significant. Unemployed students usually have higher trip rates than employed students, but the differences are not significant except for NCSU. Controversially, employed students travel significantly more than unemployed students in UNCC. Students without cars generate significantly more trips than students that have cars except FSU and UNCC where the differences are not significant. Students with parking permits make significantly more trips than those without parking permits in FSU, while students with no parking permits significantly travel more in UNCC. No statistically significant differences are found in the other universities.

Table 4.5 lists various trip rates based on the trip classifications and the student characteristics. On-campus students make significantly more within trips, but fewer crossing and outside trips than off-campus. Full-time students generate significantly more within and crossing trips, but fewer outside trips than part-time students. Graduate students have significantly fewer within trips, but more outside trips than undergraduate students. The differences in crossing trip rates are not significant. Employed students have significantly lower within trip rates, but higher crossing and outside trip rates than unemployed students. Students with cars make significantly fewer within trips, but more crossing and outside trips than those without cars. Students with parking permits have significantly fewer within trips, but more crossing trips than students without parking permits. The differences in outside trip rates are not significant.

Table 4.5 Weighted Trip Rates by Trip Classification and Student Characteristic

Student Characteristic	Within	Crossing	Outside	All
On-Campus	4.61	1.30	0.26	6.17
Off-Campus	0.79	2.25	1.99	5.02
Full-Time	2.15	2.08	1.30	5.53
Part-Time	0.42	1.53	2.49	4.44
Graduate	0.59	1.86	2.14	4.60
Undergraduate	2.11	2.01	1.38	5.49
Employed	1.41	2.02	1.83	5.27
Unemployed	2.47	1.93	1.05	5.45
Car	1.29	2.06	1.78	5.13
No Car	4.13	1.67	0.41	6.21
Parking Permit	1.53	2.00	1.62	5.15
No Parking Permit	2.13	1.97	1.41	5.51
Total	1.85	1.98	1.51	5.34

Table 4.6 Weighted Trip Rates by Trip Type and Purpose

Trip Type		Study	Go home	Work	Dining/ Shopping	Recreation/ Social	Other	Total
Within	**On-2 (UBH)**	0.68	1.08	0.04	0.25	0.19	0.01	2.26
	On-4 (UBNH)	1.28	0.00	0.07	0.64	0.36	0.02	2.38
	Off-4 (UBNH)	0.59	0.00	0.06	0.10	0.09	0.04	0.87
Crossing	**On-1 (HBNU)**	0.00	0.62	0.04	0.11	0.11	0.00	0.88
	On-3 (UBNH)	0.06	0.00	0.03	0.15	0.15	0.03	0.42
	Off-1 (UBH)	0.67	0.70	0.08	0.03	0.06	0.02	1.57
	Off-3 (UNNH)	0.21	0.00	0.07	0.20	0.14	0.06	0.68
Outside	**On-5 (NHNU)**	0.00	0.00	0.01	0.11	0.10	0.02	0.24
	Off-2 (HBNU)	0.02	0.77	0.19	0.17	0.17	0.06	1.39
	Off-5 (NHNU)	0.00	0.00	0.08	0.22	0.16	0.05	0.52
Total		1.65	1.53	0.40	0.87	0.70	0.18	5.34

Table 4.6 shows the differences in trip rates by trip type and purpose. Most of the within trips are generated from one classroom to another, between on-campus homes and classrooms, as well as between classrooms and dining halls. The off-campus ends of the crossing trips are most likely to be either off-campus homes or places for dining, shopping, recreation, and social activities. The outside trips are primarily made among off-campus homes, dining or shopping places and places for recreation or social activities.

4.2.2. Linear Regression Analysis

In addition to the cross-classification analyses, we can also use linear regression models to identify which factors may influence the trip rates most. The dependent variables for linear regression models are the daily overall trip rates, within trip rates, crossing trip rates and outside trip rates. The independent variables include the residential status, enrollment status, education status, employment status, auto ownership, and parking permit ownership.

Table 4.7 Linear Regression Model for Overall Trip Rates

Student Characteristic	Coefficient	t-Stat	Beta Weight
On Campus	0.73***	5.38	0.12
Full Time	0.39***	3.52	0.06
Graduate	-0.56***	-5.59	-0.09
Employment	0.24**	2.32	0.04
Auto Ownership	-0.39**	-2.26	-0.05
Parking Permit	-0.16	-1.56	-0.03
Constant	5.04***	25.35	-

** denotes statistical significance at the 95% level of confidence.
*** denotes statistical significance at the 99% level of confidence.
N=3,397; Adjusted R^2=0.044

Table 4.8 Linear Regression Model for Within Trip Rates

Student Characteristic	Coefficient	t-Stat	Beta Weight
On Campus	3.25***	26.37	0.54
Full Time	0.36***	6.26	0.05
Graduate	-0.27***	-4.65	-0.04
Employment	0.06	0.77	0.01
Auto Ownership	-1.13***	-7.76	-0.16
Parking Permit	-0.11	-1.70	-0.02
Constant	1.54***	10.06	-

** denotes statistical significance at the 95% level of confidence.
*** denotes statistical significance at the 99% level of confidence.
N=3,397; Adjusted R^2=0.422

Table 4.9 Linear Regression Model for Crossing Trip Rates

Student Characteristic	Coefficient	t-Stat	Beta Weight
On Campus	-1.10***	-17.10	-0.33
Full Time	0.71***	11.49	0.19
Graduate	-0.22***	-3.86	-0.06
Employment	0.04	0.75	0.01
Auto Ownership	0.00	-0.02	0.00
Parking Permit	0.15***	2.74	0.05
Constant	1.53***	15.36	-

** denotes statistical significance at the 95% level of confidence.
*** denotes statistical significance at the 99% level of confidence.
N=3,397; Adjusted R^2=0.119

Table 4.10 Linear Regression Model for Outside Trip Rates

Student Characteristic	Coefficient	t-Stat	Beta Weight
On Campus	-1.42***	-23.20	-0.32
Full Time	-0.69***	-6.85	-0.14
Graduate	-0.07	-0.81	-0.02
Employment	0.14**	2.12	0.04
Auto Ownership	0.74***	8.16	0.14
Parking Permit	-0.20**	-2.53	-0.05
Constant	1.96***	15.70	-

** denotes statistical significance at the 95% level of confidence.
*** denotes statistical significance at the 99% level of confidence.
N=3,397; Adjusted R^2=0.199

Table 4.7, Table 4.8, Table 4.9 and Table 4.10 are the results of the linear regression models for overall, within, crossing and outside trip rates. Across all the regression models, we can find that whether a university student is living on campus is a significant (represented by the asterisks for coefficients and the t-stats) and the most important (represented by the beta weights) factor for the trip rates. Full time status is also significant among all the models but has less influence on the trip rates. Whether a student is in the graduate school is significant in all of the models except the outside trip rate model. Employment status is significant for both overall and outside trip rate models. Auto ownership is a significant factor in all but crossing trip rate model. Whether having a parking permit is significant in crossing and outside trip rate models.

4.3. Trip Distance and Travel Time

The university student trips are of different trip distances and travel time across various universities, student characteristics, trip types and modes. The trip distances in the following analyses come from the network distances in the local travel demand models based on the time period of each trip. The travel time used is from the stated trip duration from the university student travel survey.

Table 4.11 Weighted Average Trip Distances and Travel Time for All Trips by University Campus

University	Weighted Average Trip Distance (Mile)	Weighted Average Travel Time (Minute)
NCSU	3.00	12.30
UNCG	3.78	11.88
ASU	1.19	9.09
FSU	4.88	14.05
UNCW	2.37	10.94
UNCC	6.11	15.78
Total	3.55	12.44

Table 4.11 lists the average trip distances and average travel time for each university campus. The trips made by students in ASU are significantly shorter in both trip distance and travel time than the other universities mainly because of the small size of the college town as well as the small model area. UNCC students make significantly longer trips in terms of trip distance and travel time probably due to the farther off-campus homes away from the campus boundary as well as the long distance from the campus to the CBD.

Table 4.12 Weighted Average Trip Distances and Travel Time for All Trips by Student Characteristic

Student Characteristic	Weighted Average Trip Distance (Mile)	Weighted Average Travel Time (Minute)
On-Campus **Off-Campus**	1.21 4.72	9.24 14.03
Full-Time **Part-Time**	3.10 6.41	11.86 16.19
Graduate **Undergraduate**	5.32 3.25	14.64 12.07
Employed **Unemployed**	4.18 2.69	13.13 11.50
Car **No Car**	4.31 1.09	13.18 10.05
Parking Permit **No Parking Permit**	4.85 2.46	13.48 11.57
Total	3.55	12.44

Table 4.12 shows how the average trip distances and average travel time change among students of different characteristics. Off-campus students make significantly longer trips than off-campus

students in trip distance and travel time. Full-time students generate trips that are significantly shorter in distance and time than part-time students. Graduate students significantly travel longer than undergraduate students in terms of both distance and travel time. Students who are employed are significantly more likely to make trips that have longer distances and travel time. Students with cars make trips that are significantly longer in distance and travel time than those without cars. Students that have parking permits travel significantly farther and longer than students with no parking permits.

Table 4.13 Weighted Average Trip Distances and Travel Time by Trip Type

Trip Type		Weighted Average Trip Distance (Mile)	Weighted Average Travel Time (Minute)
Within	**On-2 (UBH)**	0.61	8.91
	On-4 (UBNH)	0.51	7.39
	Off-4 (UBNH)	0.58	7.21
Crossing	**On-1 (HBNU)**	2.85	12.30
	On-3 (UBNH)	3.45	13.98
	Off-1 (UBH)	5.52	17.22
	Off-3 (UNNH)	5.12	15.41
Outside	**On-5 (NHNU)**	4.04	11.68
	Off-2 (HBNU)	6.09	14.41
	Off-5 (NHNU)	4.85	12.15

Table 4.13 tells the differences in trip distances and travel time among various trip types. Within trips are significantly shorter in terms of both trip distance and travel time than the other trips. Crossing trips are significantly shorter than outside trips in distance, but longer in travel time.

Table 4.14 Weighted Average Trip Distances and Travel Time for All Trips by Mode Choice

Mode Choice	Weighted Average Trip Distance (Mile)	Weighted Average Travel Time (Minute)	Average Speed (MPH)
Drive Alone	6.79	15.66	26.05
Shared Ride	4.27	12.21	20.98
Public Transit	2.99	19.95	8.99
Bicycle	1.10	9.91	6.66
Walk	0.56	8.05	4.17
Other	3.12	11.80	15.86
Total	3.55	12.44	17.12

Table 4.14 shows us how the trip distances, travel time and speeds vary from one mode to another. In terms of the average trip distance, drive alone trips are significantly longer than the other trips. Carpool trips are the second longest and transit trips are in the third place. Bike trips are longer than walk trips.

As per the average travel time, public transit trips take significantly longer time than the other trips, followed by drive alone trips, shared ride trips, bike trips and walk trips in order.

For the average speed which is calculated by dividing the network distance by the stated travel time, single-occupancy vehicle trips travel fastest. Shared ride trips are slower than the drive alone trips, but still faster than the other trips. Public transit trips are of higher speeds than walk trips, but not significantly faster than bike trips. Bike trips are significantly faster than walk trips.

4.4. Time of Day

Time of day is another key factor that makes university student trips different from each other as per the university settings, residential statuses, trip types, trip purposes as well as mode choices.

Figure 4.2 Time of Day for All Trips by University Campus

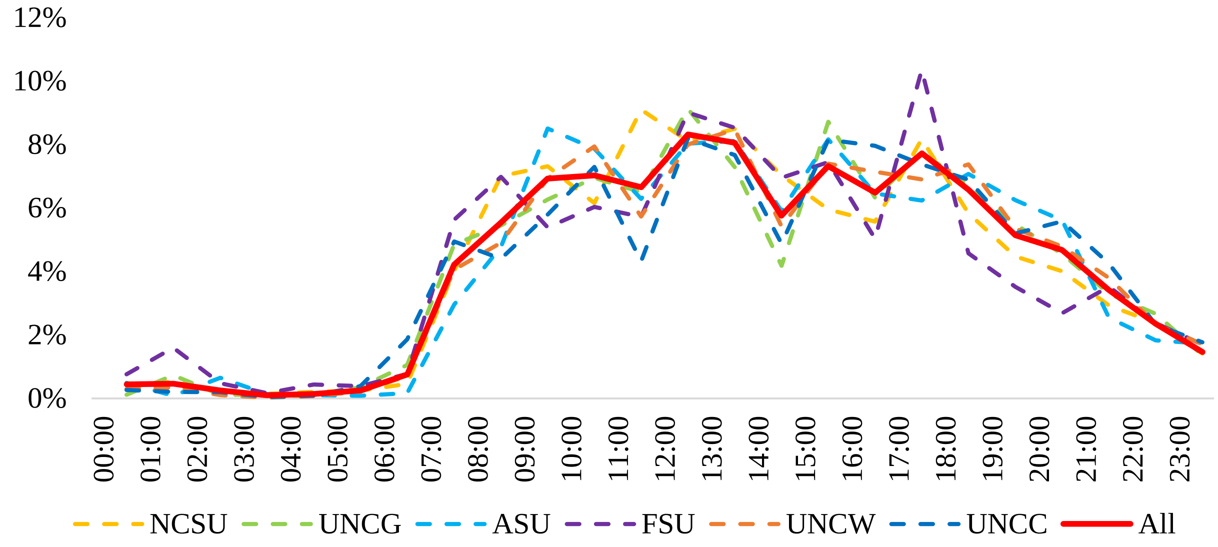
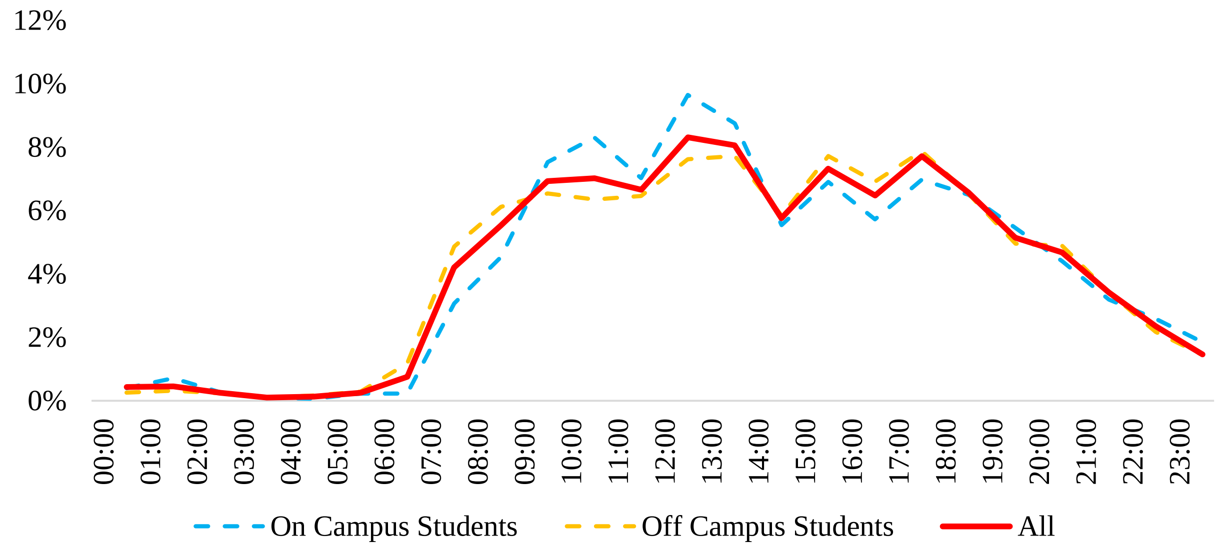


Figure 4.2 shows the differences in time of day for trips made by all of the six surveyed universities. Most of the universities follow the similar time-of-day patterns. Trips start increasing at 7 am and the AM peak falls between 9 am to 10 am. The peak hours of the whole day are identified between 12pm and 2 pm. The PM peak may occur either between 3 pm and 4 pm or between 5 pm and 6 pm.

Figure 4.3 Time of Day for All Trips by Residential Status



The variances in time of day of trips made by university students with different residential statuses are illustrated in Figure 4.3. Trips generated by on-campus students are slightly more concentrated between 9 am and 2 pm. On the other hand, trips made by off-campus students are distributed more evenly from 8 am to 6 pm.

Figure 4.4 Time of Day by Trip Classification

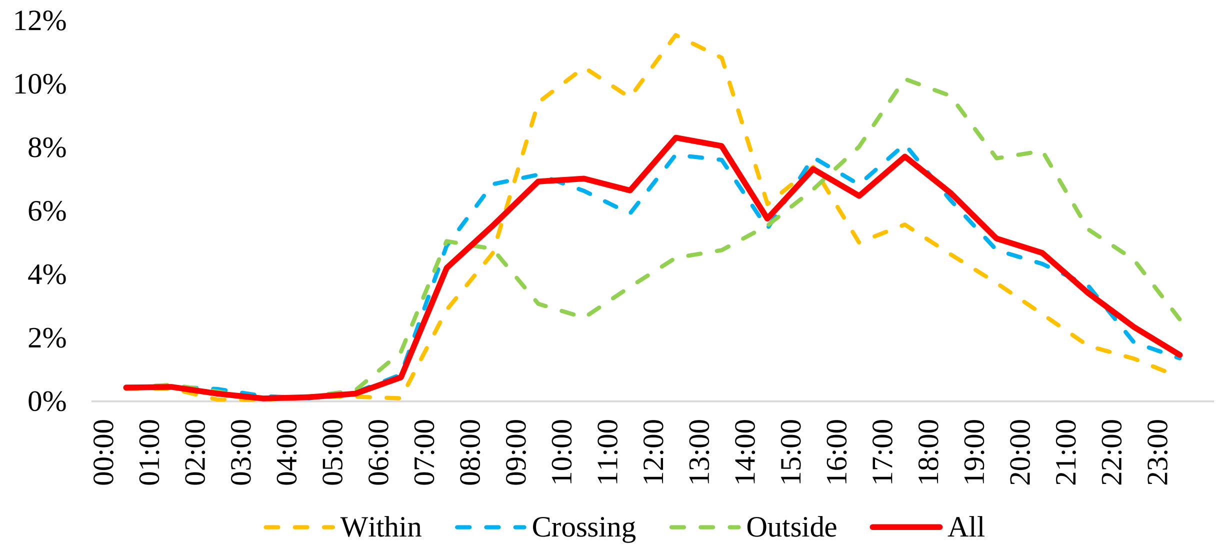


Figure 4.4 illustrates how the university student trips differ among various trip classifications. Within trips are concentrated during the school time between 9 am and 2 pm. Crossing trips are more evenly distributed from 8 am to 6 pm. Outside trips have two obvious peak periods, a lower peak in the morning from 7 am to 10 am and a higher peak in the late afternoon and evening from 4 pm to 9 pm.

Figure 4.5 Time of Day for All Trips by Purpose

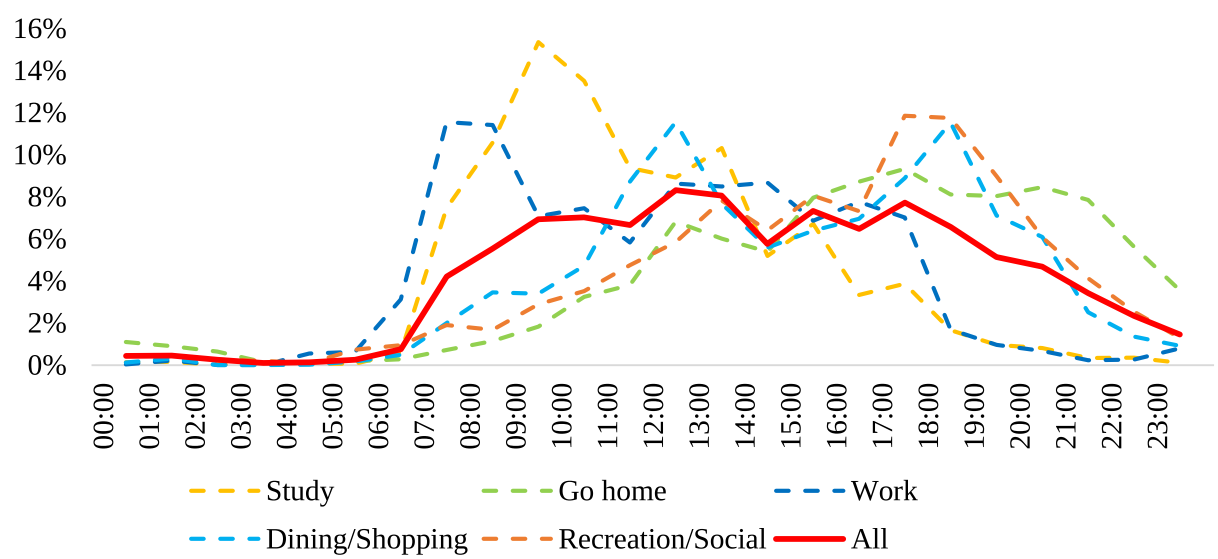
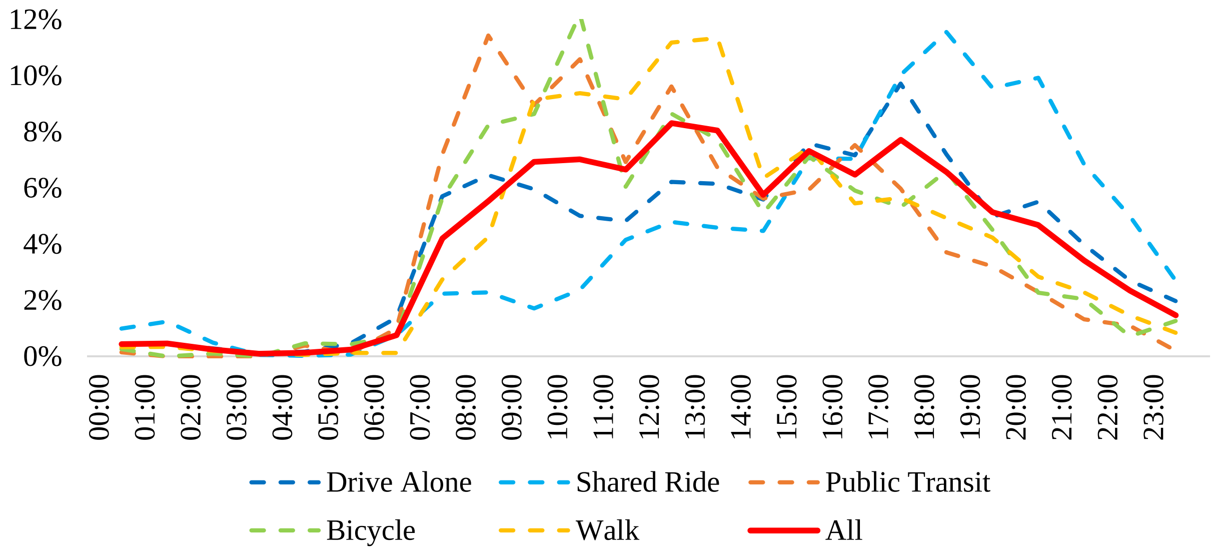


Figure 4.5 above shows that trips for attending classes peak in the morning from 8 am to 11 am and decrease continually. Home trips are constant after 12 pm till 10 pm. Work trips peak from 7 am to 9 am and stay constant between 9 am and 6 pm. Trips for dining or shopping have two identical peaks, a midday peak from 11 am to 1 pm and a PM peak from 5 pm to 8 pm. Trips for recreation or social activities are more likely to occur from 5 pm to 8 pm.

Figure 4.6 Time of Day for All Trips by Mode Choice



Mode choices also vary among different time of day as shown in Figure 4.6. Single-occupancy vehicle trips stay constant from 7 am to 5 pm, peak between 5 pm and 6 pm, and start to decrease after 6 pm. Shared ride trips increase continually until reaching the PM peak at around 6 pm to 8 pm. Public transit trips peak between 8 am to 9 am and begin to decrease after that. Bicycle trips increase from 7 am, peak between 10 am and 11 am, and decrease afterwards. Walk trips are concentrated between 9 am and 2 pm.

4.5. Mode Choice

Mode choice is also an important characteristic that university student trips may vary from the trips made by the general population. University students are more likely to choose alternative transportation modes to automobiles. The following analyses will look at the mode choices by university, student characteristic, trip type as well as trip distance in detail.

Table 4.15 Weighted Modal Shares for All Trips by University Campus

University	Drive Alone	Shared Ride	Public Transit	Bicycle	Walk	Other
NCSU	29%	10%	15%	3%	43%	0%
UNCG	35%	18%	3%	1%	42%	1%
ASU	22%	12%	13%	0%	52%	1%
FSU	57%	14%	2%	0%	27%	1%
UNCW	37%	15%	3%	11%	34%	0%
UNCC	53%	14%	3%	2%	27%	0%
Total	36%	13%	8%	3%	39%	0%

Table 4.15 demonstrates the differences in mode choices among all of the six surveyed universities. FSU and UNCC have higher percentages for automobile trips than the other universities. NCSU and ASU students tend to take public transit more than the others. UNCW has a much higher modal share for riding bicycles than the other universities. More than half of the university students' trips in ASU are made by walking.

Table 4.16 Weighted Modal Shares for All Trips by Student Characteristic

Student Characteristic	Drive Alone	Shared Ride	Public Transit	Bicycle	Walk	Other
On-Campus	8%	10%	6%	4%	71%	0%
Off-Campus	51%	15%	9%	2%	23%	1%
Full-Time	32%	13%	8%	3%	43%	1%
Part-Time	63%	14%	9%	2%	12%	0%
Graduate	57%	13%	9%	2%	19%	1%
Undergraduate	33%	13%	8%	3%	42%	0%
Employed	46%	13%	7%	3%	31%	0%
Unemployed	24%	14%	10%	3%	49%	1%
Car	47%	14%	7%	2%	29%	1%
No Car	1%	10%	12%	4%	72%	0%
Parking Permit	53%	14%	4%	2%	27%	1%
No Parking Permit	23%	13%	12%	4%	48%	0%
Total	36%	13%	8%	3%	39%	0%

Table 4.16 shows how the mode choices differ based on the student characteristics. On-campus students choose to walk most while more than half of the off-campus students' trips are done by auto vehicles. Full-time students are in favor of both driving and walking while part-time students like driving alone. Graduate students drive more while undergraduate students prefer walking more than driving alone. Employed students would like to drive while students who are

not employed prefer walking more. Students with cars drive more while those who do not have cars choose walking most. More than half of the trips generated by students who have parking permits are made by driving alone. University students without parking permits are most likely to walk.

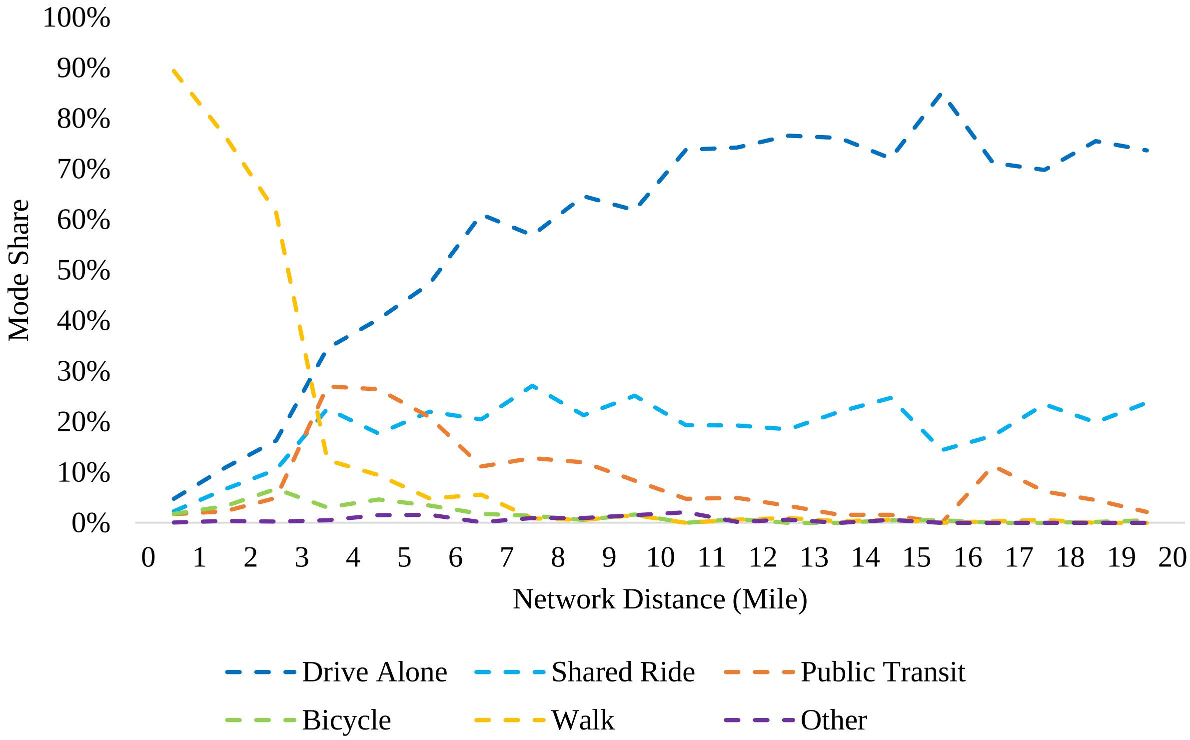
Table 4.17 Weighted Modal Shares by Trip Type

Trip Type		Drive Alone	Shared Ride	Public Transit	Bicycle	Walk	Other
Within	**On-2 (UBH)**	4%	3%	6%	6%	82%	0%
	On-4 (UBNH)	1%	1%	5%	4%	89%	0%
	Off-4 (UBNH)	7%	3%	7%	2%	81%	0%
Crossing	**On-1 (HBNU)**	23%	35%	8%	1%	33%	0%
	On-3 (UBNH)	26%	34%	12%	1%	27%	0%
	Off-1 (UBH)	48%	10%	20%	4%	17%	1%
	Off-3 (UNNH)	58%	16%	10%	2%	13%	1%
Outside	**On-5 (NHNU)**	36%	53%	4%	1%	6%	0%
	Off-2 (HBNU)	73%	21%	1%	1%	4%	1%
	Off-5 (NHNU)	61%	32%	1%	0%	5%	0%
Total		36%	13%	8%	3%	39%	0%

Table 4.17 presents the mode shares among each of the trip types. Within trips tend to be made by walking most. Crossing trips generated by on-campus students are most likely to be made through carpooling. Off-campus students prefer driving alone for crossing trips. Outside trips are dominated by automobiles. On-campus students are in favor of carpooling while off-campus students like driving alone more.

Figure 4.7 illustrates how the mode shares change based on the trip distances. Walking is the main mode for trips that are within 3 miles, but the mode share decreases sharply in longer trips. With the increase in the trip distance, the mode share of single-occupancy driving increases correspondingly and it dominates the trips that are longer than 3 miles. Shared ride trips stay at about 20% of mode share for trips that are 3 miles or more in distance. The public transit percentage peaks when the trip distance ranges from 3 to 6 miles.

Figure 4.7 Weighted Modal Shares for All Trips by Trip Distance



5. Travel Demand Model

5.1. Introduction

The travel pattern analysis section has provided a solid ground for developing the university student travel demand model based on the travel survey data collected from the six university campuses. The university student travel demand model built in this project will be primarily applied to those communities that have university or college campuses but are not able to conduct additional university student travel surveys due to the time and budget constraints. So in order to be efficiently incorporated into most of the regional travel demand models in North Carolina, conventional four-step travel demand model, which is the most widely used approach, is adopted as the foundation for the university student travel demand model developed in this project.

The model development in this section will only focus on the first three steps of the four-step travel demand model, which are trip generation, trip distribution and mode choice. A time of day and directional split model will also be built before the mode choice model in order to better model the travel flows for each hour of the day.

Only internal-internal trips, both ends of which are within the model area, will be modeled. University student trips that have at least one trip end outside the model area will be modeled together with the trips made by the general population in the travel demand model, which is beyond the scope of this project.

Similar to the idea of modeling trips with different purposes individually in the four-step travel demand model, based on the previous travel pattern analyses, the university student travel demand model will divide the student trips into five categories according to their student and trip characteristics as shown in Table 5.1.

Table 5.1 Modeled Trip Categories

Residential Status	Within	Crossing		Outside
On-Campus	Within Trip	On-Campus Student Crossing Trip		Outside Trip
Off-Campus		Off-Campus Student University-Based Home Crossing Trip	Off-Campus Student University-Based Non-Home Crossing Trip	

Within trips are the trips whose both ends locate inside the university campuses. They include on-campus student university-based home within trips (On-2), on-campus student university-based non-home within trips (On-4) and off-campus student university-based non-home within trips (Off-4). Within trips may have limited impacts on the regional networks, so only trip generation models are built for within trips for the purpose of reasonableness checks.

Crossing trips have one trip end inside the university campuses and another outside. Crossing trips may have the largest impacts on the networks near the campuses and have more potentials to build robust models, so they are the focuses of the university student travel demand models in this project. Crossing trips are divided into three categories based on the student residential statuses and the trip purposes. On-campus student crossing trips include on-campus student home-based non-university crossing trips (On-1) and on-campus student university-based non-home crossing trips (On-3). They are modeled together because of the similar characteristics in terms of off-campus trip ends, trip distances, travel time, mode choices and time of day according to the previous travel pattern analyses. Off-campus student crossing trips are separated into off-campus student university-based home crossing trips (Off-1) and off-campus student university-based non-home crossing trips (Off-3) owing to the different purposes and off-campus trip ends according the travel pattern analyses, which will lead to different trip distribution patterns. Trip generation, trip distribution, time of day and directional split, and mode choice models will be developed for each crossing trip category.

Outside trips are the trips that have both ends outside the university campuses. Although outside trips have significant impacts on the regional networks, they are not the focuses of the university student travel demand models since the models built for outside trips may not be robust considering the limited sample sizes and the complexities. Therefore, outside trips are modeled together, which include on-campus student non-home non-university outside trips (On-5), off-campus student home-based non-university outside trips (Off-2) and off-campus student non-home non-university outside trips (Off-5). For the purpose of completeness, trip generation, trip distribution, time of day and directional split, and mode choice models for outside trips are all built.

5.2. Trip Generation

Following the traditional four-step travel demand model, the first model to be developed is the trip generation model. In this section, we will only focus on the trip production models. Trip attraction models will be developed together with the trip distribution models in the next section.

Trip production models are built for each category defined in section 5.1 above. Average trip production rates are calculated for each of the six universities as well as the combination of all observed data. So modelers or planners can estimate the trip productions of their universities for each trip category by choosing the rates of the most similar universities. For within trips and outside trips, the productions and attractions are the same as origins and destinations. For crossing trips, university campuses are the productions and the non-campus zones are the attractions.

5.2.1. Within Trip

Table 5.2 Weighted Average Within Trip Rates

University	Number of Person Samples	Weighted Average Within Trip Rate	95% CI Lower Bound	95% CI Upper Bound	Weighted Average Overall Trip Rate	Percentage of Within Trips
NCSU	336	2.56	2.21	2.91	5.80	44%
UNCG	383	1.57	1.30	1.84	5.26	30%
ASU	266	1.93	1.63	2.24	5.74	34%
FSU	224	1.18	0.75	1.61	4.72	25%
UNCW	838	2.12	1.91	2.32	5.53	38%
UNCC	1,350	1.22	1.09	1.34	4.70	26%
All	3,397	1.85	1.73	1.97	5.34	35%

Figure 5.1 Weighted Average Within Trip Rates with 95% CI

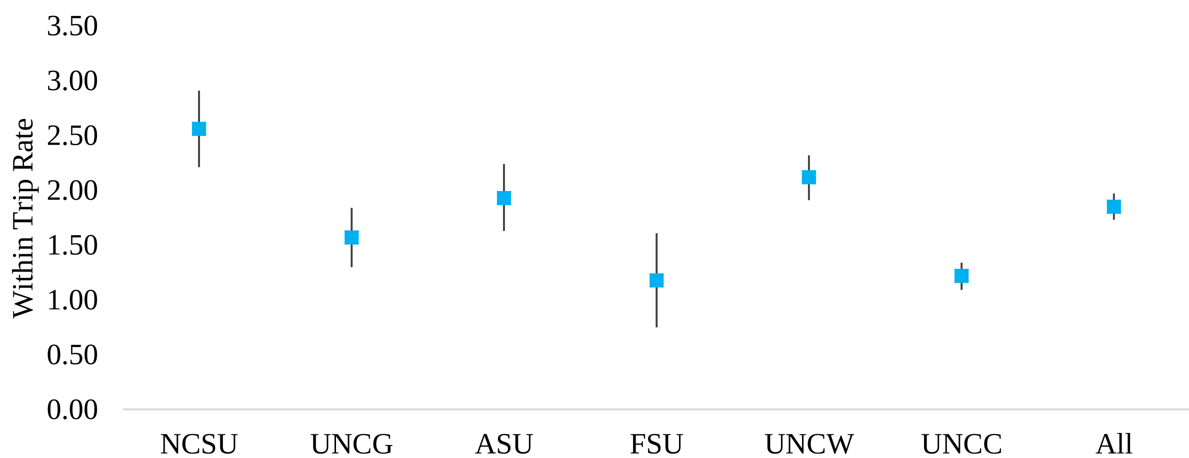


Table 5.2 and Figure 5.1 illustrate the number of person samples, the average within trip production rates and their 95% confidence intervals, the average overall trip rates, and the percentages of within trips among all trips for each of the six surveyed universities and their combined average numbers.

NCSU generally has a higher within trip rate as well as a higher percentage of within trips among all trips than the other five universities. This can be explained by its rather large campus size (2,090 acres). On the other side, FSU and UNCC have lower within trip rates and lower percentages of within trips. FSU's rather small campus size (92 acres) and UNCC's large number of off-campus students (80%) can be the main reasons. UNCG, ASU and UNCW have similar within trip rates to each other.

The control total of within trips made by university students can be calculated by multiplying the selected average within trip rate to the total number of enrolled university students. If the university has several TAZ zones inside the campus boundary, the total within trips can be disaggregated to each zone based on the zonal characteristics such as employment number or building square footage.

The within trips, by definition, will not influence the transportation network outside the university campus. Trip generation model developed for within trips will only be used for the reasonableness checks when the university student model is added to the general travel demand model. Thus, no trip distribution, mode choice or time of day models will be built for within trips in the following sections.

5.2.2. On-Campus Student Crossing Trip (On-Crossing)

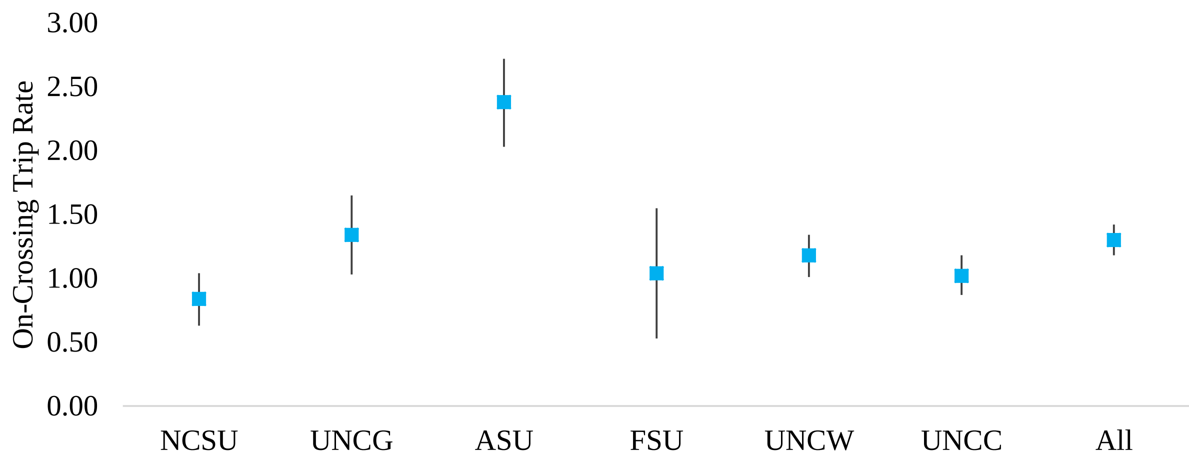
Table 5.3 Weighted Average On-Crossing Trip Rates

University	Number of Person Samples	Weighted Average On-Crossing Trip Rate	95% CI Lower Bound	95% CI Upper Bound	Weighted Average On-Campus Student Trip Rate	Percentage of On-Crossing Trips
NCSU	144	0.84	0.63	1.04	7.07	12%
UNCG	88	1.34	1.03	1.65	6.18	22%
ASU	83	2.38	2.03	2.72	6.56	36%
FSU	36	1.04	0.53	1.55	4.51	23%
UNCW	276	1.18	1.01	1.34	6.01	20%
UNCC	228	1.02	0.87	1.18	4.99	20%
All	855	1.30	1.18	1.42	6.17	21%

Table 5.3 and Figure 5.2 illustrate the number of person samples, the average on-campus student crossing trip production rates and their 95% confidence intervals, the average trip rates for on-campus students, and the percentages of crossing trips among all on-campus students' trips for each of the six surveyed universities and their combined average numbers.

ASU has a significantly higher on-crossing trip rate and also a higher percentage of on-crossing trips among all trips made by on-campus students. It is likely to be caused by its college town campus setting which indicates a closer relationship between the campus and the downtown area. NCSU generally has lower on-crossing trip rate and lower percentage of on-crossing trips mainly because of its large campus size (2,090 acres) and numerous diverse amenities within the campus. UNCG, FSU, UNCW and UNCC have similar on-crossing trip rates.

Figure 5.2 Weighted Average On-Crossing Trip Rates with 95% CI



The total number of crossing trips made by on-campus students can be calculated by multiplying the selected average on-crossing trip rate to the total number of university students living on campus. If the university has several TAZ zones inside the campus boundary, the total on-crossing trips can be disaggregated to each zone based on the zonal characteristics.

5.2.3. Off-Campus Student University-Based Home Crossing Trip (Off-1)

Table 5.4 Weighted Average Off-1 Trip Rates

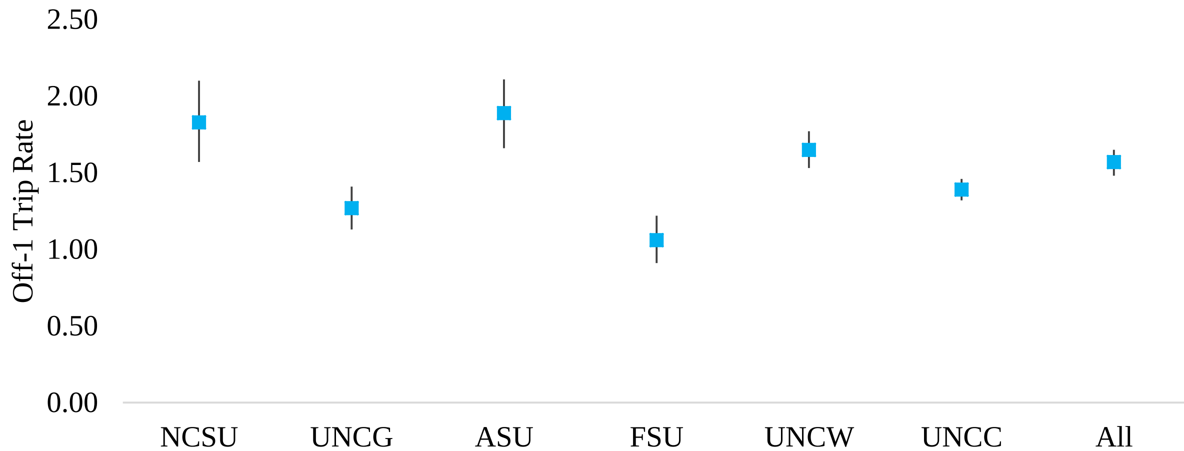
University	Number of Person Samples	Weighted Average Off-1 Trip Rate	95% CI Lower Bound	95% CI Upper Bound	Weighted Average Off-Campus Student Trip Rate	Percentage of Off-1 Trips
NCSU	192	1.83	1.57	2.10	5.28	35%
UNCG	295	1.27	1.13	1.41	4.95	26%
ASU	183	1.89	1.66	2.11	5.31	36%
FSU	188	1.06	0.91	1.22	4.8	22%
UNCW	562	1.65	1.53	1.77	5.28	31%
UNCC	1,122	1.39	1.32	1.46	4.62	30%
All	2,542	1.57	1.48	1.65	5.02	31%

Table 5.4 and Figure 5.3 show the number of person samples, the average off-campus student university-based home crossing trip production rates and their 95% confidence intervals, the

average trip rates for off-campus students, and the percentages of off-1 trips among all off-campus student trips for each of the six surveyed universities and their combined average numbers.

In general, NCSU, ASU and UNCW have higher off-1 trip rates as well as higher percentages of off-1 trips mainly because off-campus students in these three universities live closer to the campus boundaries than those in UNCG, FSU and UNCC (see Table 4.3 and Figure 4.1 for details).

Figure 5.3 Weighted Average Off-1 Trip Rates with 95% CI



The total university-based home crossing trips made by off-campus students can be calculated by multiplying the selected average off-1 trip rate to the total number of university students living off campus. If the university has several TAZ zones inside the campus boundary, the off-1 trips can be disaggregated to each zone based on the zonal characteristics.

5.2.4. Off-Campus Student University-Based Non-Home Crossing Trip (Off-3)

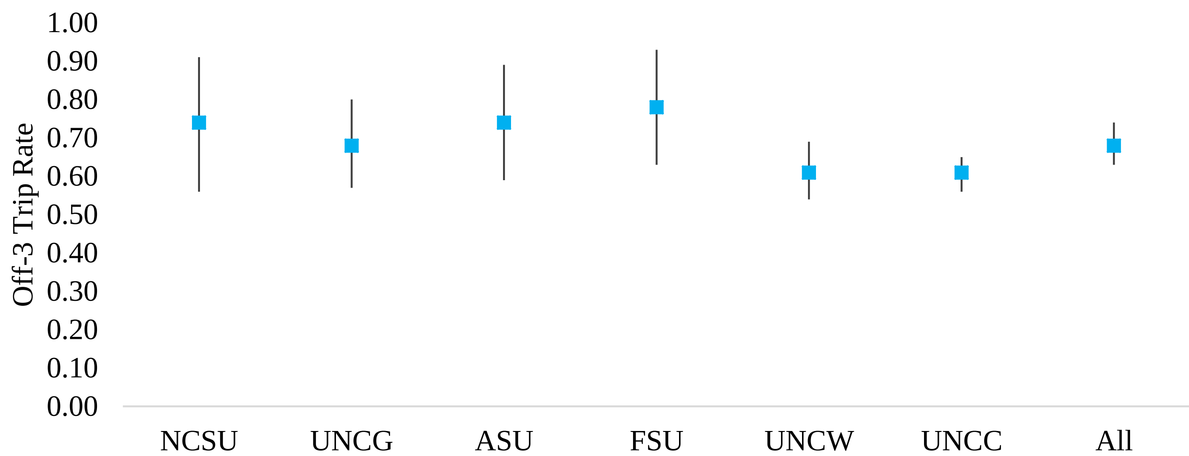
Table 5.5 Weighted Average Off-3 Trip Rates

University	Number of Person Samples	Weighted Average Off-3 Trip Rate	95% CI Lower Bound	95% CI Upper Bound	Weighted Average Off-Campus Student Trip Rate	Percentage of Off-3 Trips
NCSU	192	0.74	0.56	0.91	5.28	14%
UNCG	295	0.68	0.57	0.8	4.95	14%
ASU	183	0.74	0.59	0.89	5.31	14%
FSU	188	0.78	0.63	0.93	4.8	16%
UNCW	562	0.61	0.54	0.69	5.28	12%
UNCC	1,122	0.61	0.56	0.65	4.62	13%
All	2,542	0.68	0.63	0.74	5.02	14%

Table 5.5 and Figure 5.4 demonstrate the number of person samples, the average off-campus student university-based non-home crossing trip production rates and their 95% confidence intervals, the average trip rates for off-campus students, and the percentages of off-3 trips among all off-campus student trips for each of the six surveyed universities and their combined average numbers.

The average off-3 trip rates across all the six surveyed universities are similar to each other. UNCW and UNCC have slightly lower off-3 trip rates and lower percentages of off-3 trips probably due to their suburban campus settings.

Figure 5.4 Weighted Average Off-3 Trip Rates with 95% CI



The control total of university-based non-home crossing trips made by off-campus students can be computed by multiplying the selected average off-3 trip rate to the total number of off-campus university students. If the university has several TAZ zones inside the campus boundary, the off-3 trips can be disaggregated to each zone based on the zonal characteristics.

5.2.5. Outside Trip

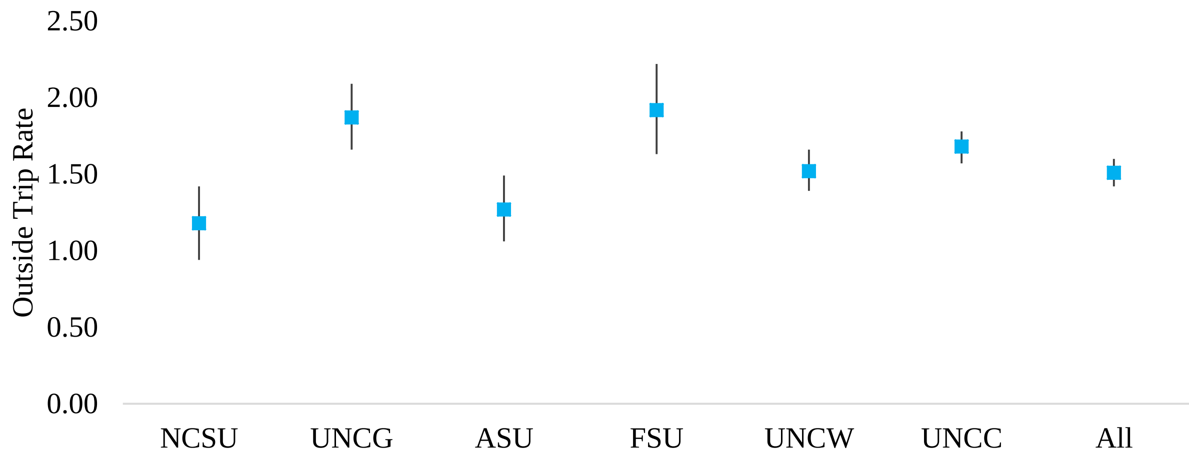
Table 5.6 Weighted Average Outside Trip Rates

University	Number of Person Samples	Weighted Average Outside Trip Rate	95% CI Lower Bound	95% CI Upper Bound	Weighted Average Overall Trip Rate	Percentage of Outside Trips
NCSU	336	1.18	0.94	1.42	5.8	20%
UNCG	383	1.87	1.66	2.09	5.26	36%
ASU	266	1.27	1.06	1.49	5.74	22%
FSU	224	1.92	1.63	2.22	4.72	41%
UNCW	838	1.52	1.39	1.66	5.53	27%
UNCC	1,350	1.68	1.57	1.78	4.7	36%
All	3,397	1.51	1.42	1.60	5.34	28%

Table 5.6 and Figure 5.5 show the number of person samples, the average outside trip production rates and their 95% confidence intervals, the average overall trip rates, and the percentages of outside trips among all trips for each of the six surveyed universities and their combined average numbers.

UNCG and FSU generally have higher outside trip rates and higher percentages of outside trips while NCSU and ASU have lower outside trip rates and percentages. The differences are likely to be caused by the campus sizes and the quality of amenities provided by the university campuses since UNCG and FSU have much smaller campus sizes (231 acres for UNCG and 92 acres for FSU) compared to NCSU and ASU (2,090 acres for NCSU and 1,732 acres for ASU).

Figure 5.5 Weighted Average Outside Trip Rates with 95% CI



The total number of outside trips made by university students can be calculated by multiplying the selected average outside trip rate to the total number of enrolled university students. If the university has several TAZ zones inside the campus boundary, the total within trips can be disaggregated to each zone based on the zonal characteristics such as employment number or building square footage.

5.3. Trip Distribution

The second step of the four-step travel demand model is trip distribution. Gravity Model will be used for developing the trip distribution model. The function for Gravity Model is:

$$\boldsymbol{T_{ij} = P_i \cdot \frac{A_j \cdot FF_{ij}}{\sum_z A_z \cdot FF_{iz}}} \qquad \textbf{\textit{(5-1)}}$$

Where:

$\boldsymbol{T_{ij}}$ = the number of trips produced by zone $\boldsymbol{i}$ and attracted to zone $\boldsymbol{j}$
$\boldsymbol{P_i}$ = the number of trips produced by zone $\boldsymbol{i}$
$\boldsymbol{A_j}$ **=** the number of trips attracted to zone $\boldsymbol{j}$
$\boldsymbol{FF_{ij}}$ = the friction factor between zone $\boldsymbol{i}$ and zone $\boldsymbol{j}$
$\boldsymbol{z}$ = all zones

Trip attraction models need to be developed for $\boldsymbol{A_j}$**.** The attraction can be surrogated by the zonal population and employment from the socio-economic data. So the function for $\boldsymbol{A_j}$ will become:

$$\boldsymbol{A_j = f(Emp_j, Pop_j)} \qquad \textbf{\textit{(5-2)}}$$

Where:

$\boldsymbol{Emp_j}$ = the employment in zone $\boldsymbol{j}$
$\boldsymbol{Pop_j}$ = the population in zone $\boldsymbol{j}$

For the friction factor, Gamma Function will be used which is a function of the impedance. The Gamma Function for FF_{ij} is:

$$\boldsymbol{FF_{ij} = a \cdot d_{ij}^{-b} \cdot e^{-c \cdot (d_{ij})}} \qquad \textbf{\textit{(5-3)}}$$

Where:

$\boldsymbol{d_{ij}}$ = the impedance between zone $\boldsymbol{i}$ and zone $\boldsymbol{j}$
$\boldsymbol{a}$, $\boldsymbol{b}$ and $\boldsymbol{c}$ are the coefficients ($\boldsymbol{a} > 0$; $\boldsymbol{c} \geq 0$)

Trip distribution models are developed for three crossing trip categories and one outside trip category defined in section 5.1 for each of the six universities and the combination of all observed data. So modelers or planners can distribute the trips produced from the trip generation models by choosing the Gravity Models of the most similar universities.

5.3.1. On-Campus Student Crossing Trip (On-Crossing)

In order to figure out the attraction function for on-campus student crossing trips that will be used in the Gravity Model, a linear regression model is built as shown in Table 5.7. The outcome variable is the number of on-crossing trips attracted to each TAZ zone. The independent variables are the population, employments of industry, retail, service and office, and the network distance to campus central TAZ.

Table 5.7 Linear Regression Model for On-Crossing Trip Attractions

TAZ Characteristic	Coefficient	t-Stat	Beta Weight
Population	-0.003**	-2.280	-0.023
Industry	-0.005**	-2.350	-0.024
Retail	0.036***	8.440	0.089
Service	0.020***	9.670	0.100
Office	-0.002	-1.460	-0.015
Network Distance to Campus Central TAZ	-0.379***	-6.410	-0.065
Constant	10.021***	5.870	-

** denotes statistical significance at the 95% level of confidence.
*** denotes statistical significance at the 99% level of confidence.
N=9,555; Adjusted R^2=0.025

The linear regression analysis shows that the network distance to campus central TAZ and the employments of retail and service are the most significant and important factors that make TAZs attractive to on-crossing trips.

The result is consistent with the implication from the cross-classification analysis of trip rates by trip type and purpose in Table 4.6, which indicates that the off-campus ends of the on-crossing trips are most likely to be places for dining, shopping, recreation, and social activities.

Thus, the attraction function for on-crossing trips can be a combination of the zonal retail employment and the service employment:

$$\boldsymbol{f(Emp_j, Pop_j) = Retail_j + Service_j} \qquad \textit{(5-4)}$$

Where: $\boldsymbol{Retail_j}$ **=** the employment of retail sector in zone $\boldsymbol{j}$
$\boldsymbol{Service_j}$ = the employment of service sector in zone $\boldsymbol{j}$

According to the attraction function 5-4 above, the function of the Gravity Model for on-crossing trips can be rewritten as:

$$\boldsymbol{T_{cj} = P_c \cdot \frac{(Retail_j + Service_j) \cdot FF_{cj}}{\sum(Retail_z + Service_z) \cdot FF_{cz}}} \qquad \textit{(5-5)}$$

Where: $\boldsymbol{T_{cj}}$ = the number of trips between campus zone and non-campus zone $\boldsymbol{j}$
$\boldsymbol{P_c}$ = the number of trips produced by campus zone
$\boldsymbol{FF_{cj}}$ **=** the friction factor between campus zone and non-campus zone $\boldsymbol{j}$
$\boldsymbol{z}$ = all non-campus zones

Based on the observed travel survey data from the six university campuses as well as the socio-economic data for each TAZ in the local travel demand models, we can estimate the friction factors for on-crossing trips which are functions based on the network distances to campus central TAZs.

In order to figure out the coefficients of Gamma Functions for the friction factors directly through linear regression models, we can rewrite the Gamma Function as:

$$\boldsymbol{ln(FF_{cj}) = ln(a \cdot d_{cj}^{-b} \cdot e^{-c*d_{cj}}) = ln(a) - b \cdot ln(d_{cj}) - c \cdot d_{cj}} \qquad \textbf{\textit{(5-6)}}$$

Where: $\boldsymbol{d_{cj}}$ = the network distance from the campus central TAZ to non-campus zone $\boldsymbol{j}$
$\boldsymbol{a} = \boldsymbol{e^{constant}}$
$\boldsymbol{b}$ = negative of the coefficient for $\boldsymbol{ln(d_{cj})}$
$\boldsymbol{c}$ = negative of the coefficient for $\boldsymbol{d_{cj}}$

Figure 5.6 shows the observed standardized friction factors as well as the modeled friction factors for on-crossing trips based on the Gamma Functions developed for each of the six universities except FSU and the combined data. FSU has a rather small sample size and no satisfactory model can be built. The flatter curve represents higher tolerance of the impedance, which indicates that the university students are more likely to make longer trips.

Figure 5.6 Observed Friction Factors and Gamma Function Models for On-Crossing Trips

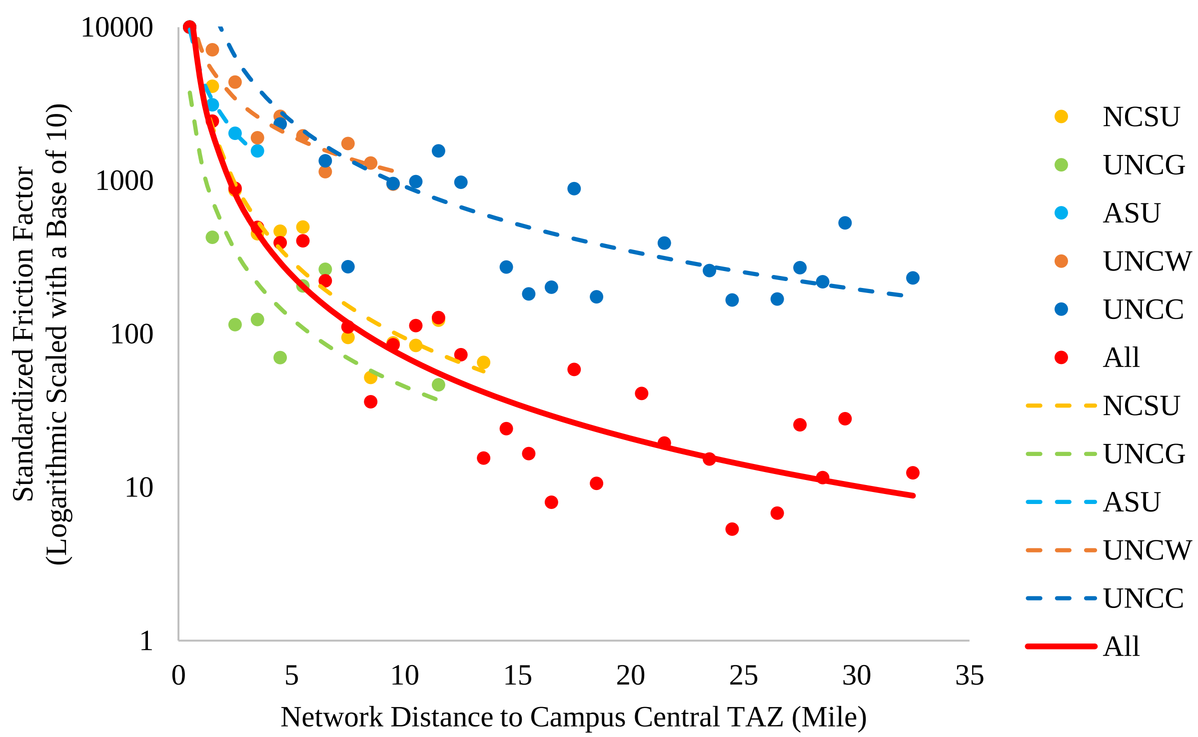


Table 5.8 below demonstrates the number of trip samples, the coefficients of Gamma Functions for on-crossing trips, as well as the fitness of the models.

Table 5.8 Gamma Function Coefficients for On-Crossing Trips

University	Number of Trip Samples	Ln(a)	b	c	Adjusted R2
NCSU	128	8.393	1.672	0.000	0.919
UNCG	112	7.208	1.473	0.000	0.696
ASU	189	8.508	0.963	0.000	0.993
UNCW	323	8.887	0.815	0.000	0.888
UNCC	229	10.064	1.408	0.000	0.726
All	1,013	8.340	1.771	0.000	0.877

Thus, the number of on-crossing trips obtained from the trip generation model in section 5.2.2 can be distributed based on the Equation 5-5 with the selected Gamma Function for friction factors.

5.3.2. Off-Campus Student University-Based Home Crossing Trip (Off-1)

Similar to the procedures for the on-campus student crossing trips, a linear regression analysis for the off-campus student university-based home crossing trip attractions is developed as shown in Table 5.9.

Table 5.9 Linear Regression Model for Off-1 Trip Attractions

TAZ Characteristic	Coefficient	t-Stat	Beta Weight
Population	0.013***	3.940	0.068
Industry	-0.005	-1.820	-0.015
Retail	0.014	1.820	0.020
Service	0.011	0.970	0.033
Office	-0.003	-1.750	-0.013
Network Distance to Campus Central TAZ	-1.178***	-8.490	-0.123
Constant	28.592***	7.570	-

** denotes statistical significance at the 95% level of confidence.
*** denotes statistical significance at the 99% level of confidence.
N=9,555; Adjusted R^2=0.023

The linear regression analysis shows that the network distance to campus central TAZ and the population are the most significant and important factors that make TAZs attractive to off-1 trips. The result is consistent with the definition of off-1 trip, which is made between the university campus and the off-campus home. Thus, the attraction function for off-1 trips will be:

$$f(Emp_j, Pop_j) = Pop_j \qquad (5\text{-}7)$$

Where: Pop_j = the population in zone j

According to the attraction function 5-7 above, the function of the Gravity Model for off-1 trips can be rewritten as:

$$T_{cj} = P_c \cdot \frac{Pop_j \cdot FF_{cj}}{\sum Pop_z \cdot FF_{cz}} \qquad (5\text{-}8)$$

Based on the observed travel survey data from the six university campuses as well as the socio-economic data for each TAZ in the local travel demand models, we can develop linear regression models based on Equation 5-6 to estimate the Gamma Functions for off-1 trips.

Figure 5.7 Observed Friction Factors and Gamma Function Models for Off-1 Trips

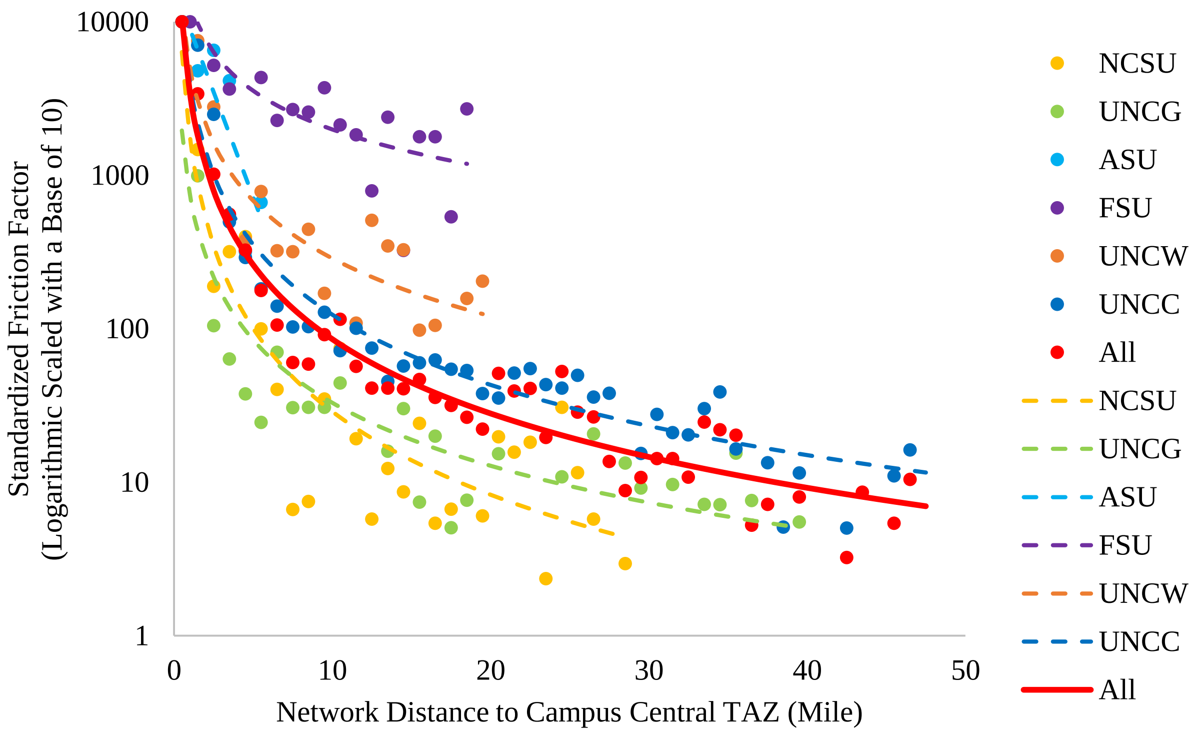


Figure 5.7 illustrates the observed standardized friction factors as well as the modeled friction factors based on the Gamma Functions developed for each of the six universities and the combined data. The flatter curve represents higher tolerance of the impedance, which indicates that the university students are more likely to make longer trips.

Table 5.10 Gamma Function Coefficients for Off-1 Trips

University	Number of Trip Samples	Ln(a)	b	c	Adjusted R^2
NCSU	338	7.509	1.801	0.000	0.786
UNCG	369	6.637	1.363	0.000	0.820
ASU	310	9.741	0.000	0.633	0.669
FSU	179	9.528	0.838	0.000	0.497
UNCW	875	8.539	1.249	0.000	0.809
UNCC	1,519	8.320	1.521	0.000	0.917
All	3,590	8.153	1.608	0.000	0.927

Table 5.10 lists the number of trip samples, the coefficients of Gamma Functions for off-1 trips, as well as the fitness of the models.

Thus, the number of off-1 trips obtained from the trip generation model in section 5.2.3 can be distributed based on the Equation 5-8 with the selected Gamma Function for friction factors.

5.3.3. Off-Campus Student University-Based Non-Home Crossing Trip (Off-3)

Similar to the procedures for the on-campus student crossing trips, a linear regression analysis for the off-campus student university-based non-home crossing trip attractions is developed as shown in Table 5.11.

Table 5.11 Linear Regression Model for Off-3 Trip Attractions

TAZ Characteristic	Coefficient	t-Stat	Beta Weight
Population	0.000	0.290	0.003
Industry	-0.004	-1.890	-0.019
Retail	0.037***	9.050	0.095
Service	0.016***	8.050	0.083
Office	-0.001	-0.590	-0.006
Network Distance to Campus Central TAZ	-0.481***	-8.590	-0.087
Constant	12.035***	7.460	-

** denotes statistical significance at the 95% level of confidence.
*** denotes statistical significance at the 99% level of confidence.
N=9,555; Adjusted R^2=0.027

The linear regression analysis shows that the network distance to campus central TAZ and the employments of retail and service are the most significant and important factors that make TAZs attractive to off-3 trips.

The result is consistent with the implication from the cross-classification analysis of trip rates by trip type and purpose in Table 4.6, which indicates that the off-campus ends of off-3 trips are most likely to be places for dining, shopping, recreation, and social activities.

Thus, the attraction function for off-3 trips can be a combination of the zonal retail employment and the service employment as Equation 5-4 shows. The function of the Gravity Model for off-3 trips can be rewritten as Equation 5-5.

Based on the observed travel survey data from the six university campuses as well as the socio-economic data for each TAZ in the local travel demand models, we can develop linear regression models based on Equation 5-6 to estimate the Gamma Functions for off-3 trips.

Figure 5.8 illustrates the observed standardized friction factors as well as the modeled friction factors based on the Gamma Functions developed for each of the six universities except FSU and the combined data. No satisfactory model can be built for FSU. The flatter curve represents higher tolerance of the impedance, which indicates that the university students are more likely to make longer trips.

Figure 5.8 Observed Friction Factors and Gamma Function Models for Off-3 Trips

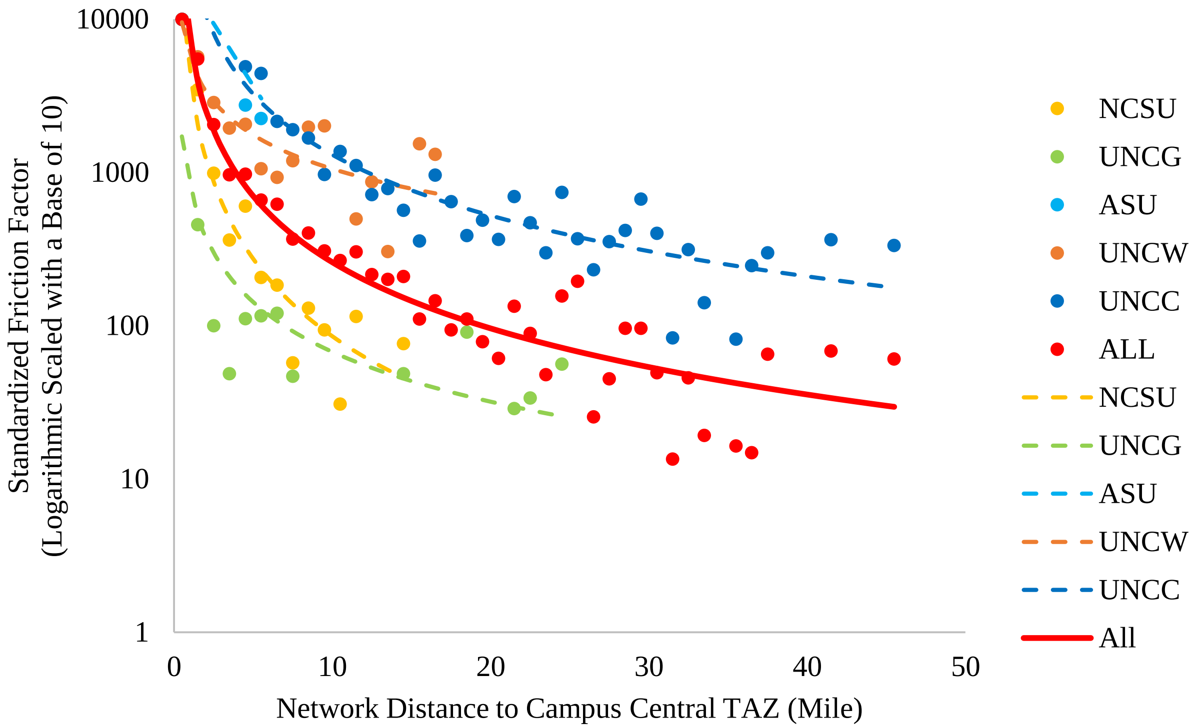


Table 5.12 shows the number of trip samples, the coefficients of Gamma Functions for off-3 trips, as well as the fitness of the models.

Table 5.12 Gamma Function Coefficients for Off-3 Trips

University	Number of Trip Samples	Ln(a)	b	c	Adjusted R^2
NCSU	132	8.316	1.681	0.000	0.899
UNCG	194	6.701	1.080	0.000	0.664
ASU	129	10.079	0.000	0.374	0.464
UNCW	330	8.655	0.736	0.000	0.650
UNCC	677	10.209	1.318	0.000	0.811
All	1,610	8.860	1.434	0.000	0.872

Thus, the number of off-3 trips obtained from the trip generation model in section 5.2.4 can be distributed based on the Equation 5-5 with the selected Gamma Function for friction factors.

5.3.4. Outside Trip

Similar to the procedures for the on-campus student crossing trips, a linear regression analysis for the outside trip attractions is developed as shown in Table 5.13.

Table 5.13 Linear Regression Model for Outside Trip Attractions

TAZ Characteristic	Coefficient	t-Stat	Beta Weight
Population	0.013***	12.100	0.118
Industry	-0.001	-0.350	-0.003
Retail	0.071***	18.240	0.184
Service	0.006***	3.090	0.031
Office	0.004***	2.910	0.029
Network Distance to Campus Central TAZ	-1.075***	-20.110	-0.196
Constant	24.854***	16.120	-

** denotes statistical significance at the 95% level of confidence.
*** denotes statistical significance at the 99% level of confidence.
N=9,555; Adjusted R^2=0.103

The linear regression shows that the network distance to campus central TAZ, the population, and the employments of retail, service and office are all significant factors that make TAZs attractive to outside trips.

The network distance to campus central TAZ is not the distance between production zone and attraction zone for outside trips. However, it is still a significant and the most important factor as illustrated in Table 5.13. In other words, TAZs closer to campus are more likely to produce and attract outside trips. So the Gravity Model for outside trips will still use the network distance to campus central TAZ as the impedance.

The result of the linear regression model in Table 5.13 is consistent with the implication from the cross-classification analysis of trip rates by trip type and purpose in Table 4.6, which indicates that the outside trips are most likely to be made between homes and places for working, dining, shopping, recreation, and social activities.

Thus, the attraction function for outside trips can be a combination of the population and the employments of retail, service and office. Considering that the total number of population can be much larger than the total number of retail, service and office employment in the region, the impact of population on the attractiveness of the zones will be exaggerated. Therefore, we need adjustment factors to balance the influence of population and employment based on their total numbers. Then the attraction function for outside trips will become:

$$f(Emp_j, Pop_j) = Pop_j + \frac{Regional\,Total\,Pop}{Regional\,Total\,Emp} \cdot (Retail_j + Service_j + Office_j) \qquad \textit{(5-9)}$$

Where: $Regional\,Total\,Pop$ = the total population of all zones
$Regional\,Total\,Emp$ = the total retail, service and office employments of all zones
$Office_j$= the employment of office sector in zone j

The adjustment factors are the regional total population over the regional total employments of retail, service and office in the modeled areas that come from the socio-economic data in the local travel demand models. The regional total employment does not include industry that is not significant in the previous linear regression model as shown in Table 5.13. Table 5.14 lists the adjustment factors for each of the six universities surveyed as well as the combined data.

Table 5.14 Regional Total Population and Employment

University	Regional Total Pop	Regional Total Retail	Regional Total Service	Regional Total Office	Regional Total Pop/ Regional Total Emp
NCSU	1,589,115	129,040	315,827	270,784	2.221
UNCG	1,156,928	161,629	232,197	100,966	2.338
ASU	20,081	6,862	10,207	2,084	1.048
FSU	521,335	41,946	58,491	39,000	3.739
UNCW	263,361	32,553	39,288	12,035	3.140
UNCC	2,222,559	228,393	229,978	313,913	2.878
All	5,773,379	600,423	885,988	738,782	2.595

According to the attraction equation 5-9 above, the function of the Gravity Model for outside trips can be rewritten as:

$$T_{cj} = P_c \cdot \frac{(Pop_j + \frac{Regional\,Total\,Pop}{Regional\,Total\,Emp} \cdot (Retail_j + Service_j + Office_j)) \cdot FF_{cj}}{\sum (Pop_z + \frac{Regional\,Total\,Pop}{Regional\,Total\,Emp} \cdot (Retail_z + Service_z + Office_z)) \cdot FF_{cz}} \qquad \textit{(5-10)}$$

Based on the observed travel survey data from the six university campuses as well as the socio-economic data for each TAZ in the local travel demand models, we can develop linear regression models based on Equation 5-6 to estimate the Gamma Functions for outside trips.

Figure 5.9 illustrates the observed standardized friction factors as well as the modeled friction factors based on the Gamma Functions developed for each of the six universities except FSU and the combined data. No satisfactory model can be built for FSU. The flatter curve represents higher tolerance of the impedance, which indicates that the university students are more likely to make longer trips.

Figure 5.9 Observed Friction Factors and Gamma Function Models for Outside Trips

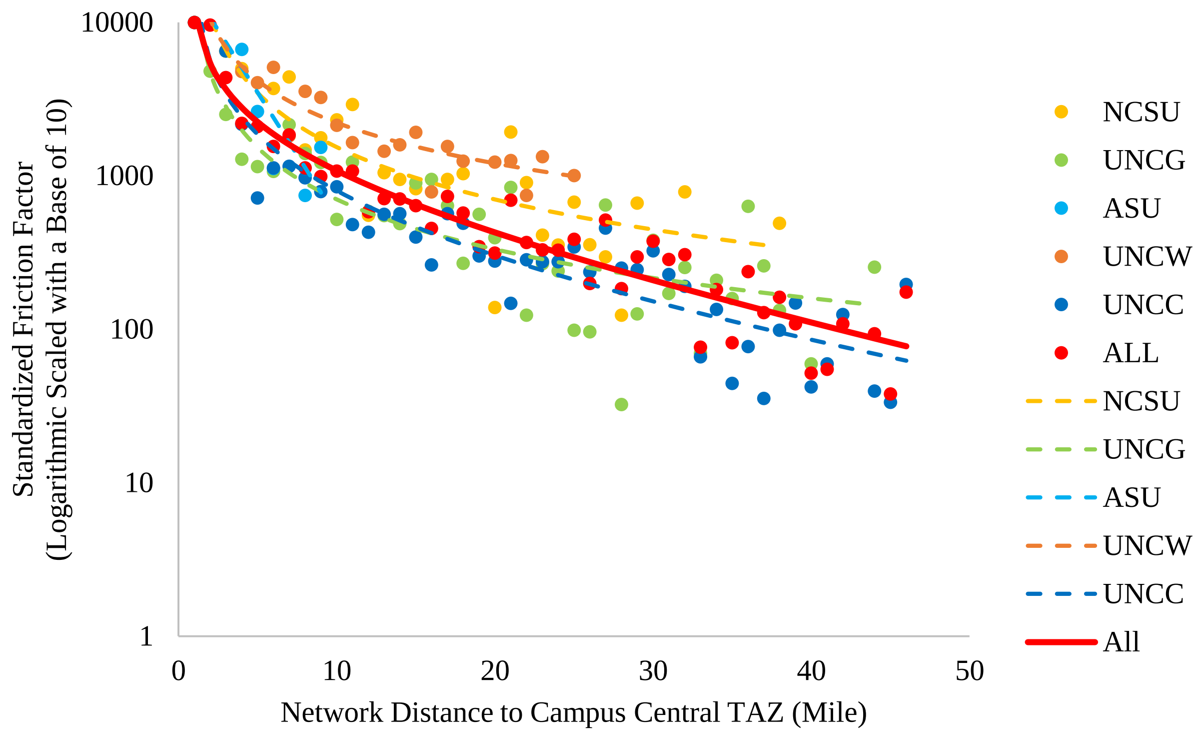


Table 5.15 demonstrates the number of trip samples, the coefficients of Gamma Functions for outside trips, as well as the fitness of the models.

Table 5.15 Gamma Function Coefficients for Outside Trips

University	Number of Trip Samples	Ln(a)	b	c	Adjusted R2
NCSU	324	9.794	1.092	0.000	0.708
UNCG	604	8.899	1.042	0.000	0.693
ASU	251	9.845	0.000	0.375	0.752
UNCW	1,004	9.615	0.848	0.000	0.793
UNCC	2,243	9.061	0.927	0.031	0.846
All	4,790	8.947	0.687	0.043	0.893

Thus, the number of outside trips obtained from the trip generation model in section 5.2.2 can be distributed based on the Equation 5-10 with the selected Gamma Function for friction factors.

5.3.5. Calibration Target

Table 5.16 Weighted Average Trip Distances by Trip Category and University Campus

University	On-Crossing	Off-1	Off-3	Outside
NCSU	3.23	4.93	4.37	5.38
UNCG	4.08	5.91	4.72	5.41
ASU	0.85	1.94	1.82	2.16
FSU	4.65	8.27	6.85	5.76
UNCW	3.25	3.36	3.47	4.27
UNCC	6.67	8.63	8.36	7.58
All	3.05	5.52	5.12	5.67

Table 5.16 lists the weighted average trip distances by trip category for each of the six surveyed universities and the combined data. The average trip distances can be used for modelers or planners to calibrate the models developed through the above trip generation and trip distribution steps. The modeled average trip distances should be close to the observed average trip distances.

5.4. Time of Day and Directional Split

With the trip generation and trip distribution models, we can obtain the daily trips produced by one zone and attracted to another. In order to figure out the numbers of trips originated from one zone and to another as per the time of day, we need to build time of day models as well as directional split models.

According to the previous time-of-day analyses in section 4.4, the time patterns of all the six universities are similar. Also considering the limited sample sizes, only one time of day and directional split model is developed here for each trip type by using the combined data of all the six universities surveyed.

Table 5.17 lists the percentages of trips for each hour of day as well as each direction based on the trip production zones.

Table 5.17 Weighted Percentages of Trips for Each Hour and Direction by Trip Category

Time of Day	On Crossing		Off-1		Off-3		Outside	
	Depart	Return	Depart	Return	Depart	Return	Depart	Return
00:00-01:00	0.19%	0.75%	0.46%	0.06%	0.00%	0.00%	0.22%	0.22%
01:00-02:00	0.30%	0.86%	0.24%	0.19%	0.00%	0.03%	0.26%	0.26%
02:00-03:00	0.60%	0.30%	0.25%	0.00%	0.34%	0.00%	0.16%	0.16%
03:00-04:00	0.19%	0.00%	0.04%	0.04%	0.04%	0.34%	0.03%	0.03%
04:00-05:00	0.00%	0.00%	0.06%	0.11%	0.00%	0.00%	0.08%	0.08%
05:00-06:00	0.19%	0.08%	0.10%	0.22%	0.17%	0.04%	0.17%	0.17%
06:00-07:00	0.04%	0.64%	0.15%	0.83%	0.56%	0.12%	0.78%	0.78%
07:00-08:00	0.23%	0.99%	0.29%	7.07%	0.00%	1.93%	2.53%	2.53%
08:00-09:00	0.37%	1.43%	0.13%	9.45%	0.67%	3.55%	2.41%	2.41%
09:00-10:00	0.45%	0.78%	1.17%	8.92%	1.42%	3.28%	1.54%	1.54%
10:00-11:00	2.32%	0.99%	1.87%	6.78%	1.82%	2.57%	1.32%	1.32%
11:00-12:00	2.97%	0.99%	2.22%	3.51%	4.35%	3.43%	1.80%	1.80%
12:00-13:00	3.96%	3.09%	4.02%	2.66%	7.84%	3.01%	2.26%	2.26%
13:00-14:00	3.38%	2.49%	3.20%	3.40%	6.50%	4.73%	2.39%	2.39%
14:00-15:00	2.13%	3.19%	2.94%	1.81%	4.79%	2.39%	2.77%	2.77%
15:00-16:00	5.02%	3.56%	4.38%	2.05%	6.97%	3.02%	3.34%	3.34%
16:00-17:00	3.03%	5.68%	4.55%	1.40%	5.60%	1.90%	4.01%	4.01%
17:00-18:00	4.08%	4.79%	4.50%	2.00%	7.63%	3.64%	5.08%	5.08%
18:00-19:00	2.71%	5.80%	2.90%	1.93%	5.78%	2.50%	4.81%	4.81%
19:00-20:00	2.86%	6.27%	2.96%	0.83%	3.16%	0.73%	3.83%	3.83%
20:00-21:00	2.79%	5.53%	3.07%	0.80%	2.09%	0.43%	3.95%	3.95%
21:00-22:00	2.07%	3.97%	3.43%	0.38%	1.04%	0.50%	2.71%	2.71%
22:00-23:00	1.09%	3.56%	1.39%	0.11%	0.54%	0.17%	2.23%	2.23%
23:00-24:00	0.85%	2.46%	0.96%	0.21%	0.28%	0.10%	1.30%	1.30%
Total	41.79%	58.21%	45.27%	54.73%	61.56%	38.44%	50.00%	50.00%

Figure 5.10, Figure 5.11, Figure 5.12 and Figure 5.13 illustrate the percentages of trips that depart and return to the production zones as well as the total trips for each trip category and each hour of the day.

Figure 5.10 Time of Day and Directional Split for On-Crossing Trips

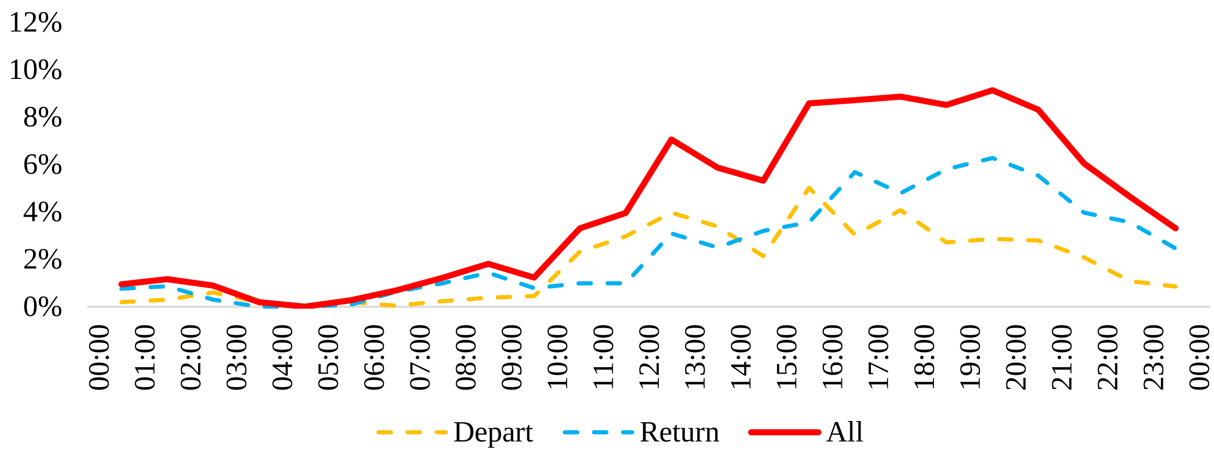


Figure 5.11 Time of Day and Directional Split for Off-1 Trips

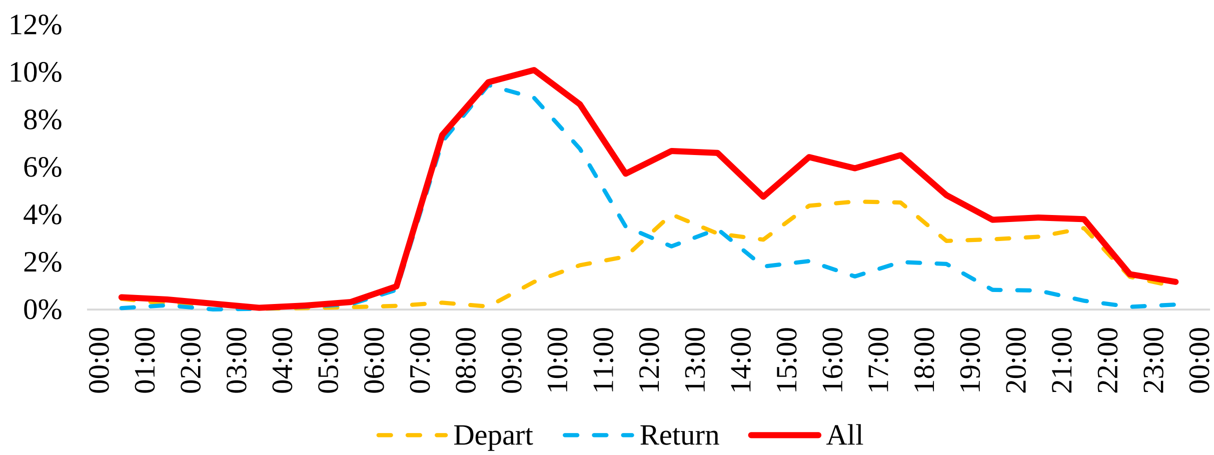


Figure 5.12 Time of Day and Directional Split for Off-3 Trips

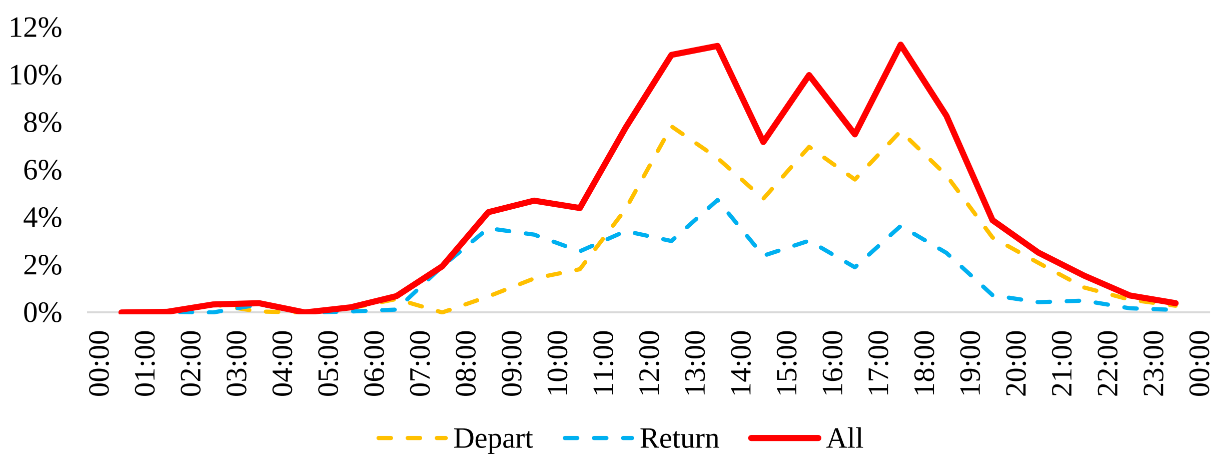
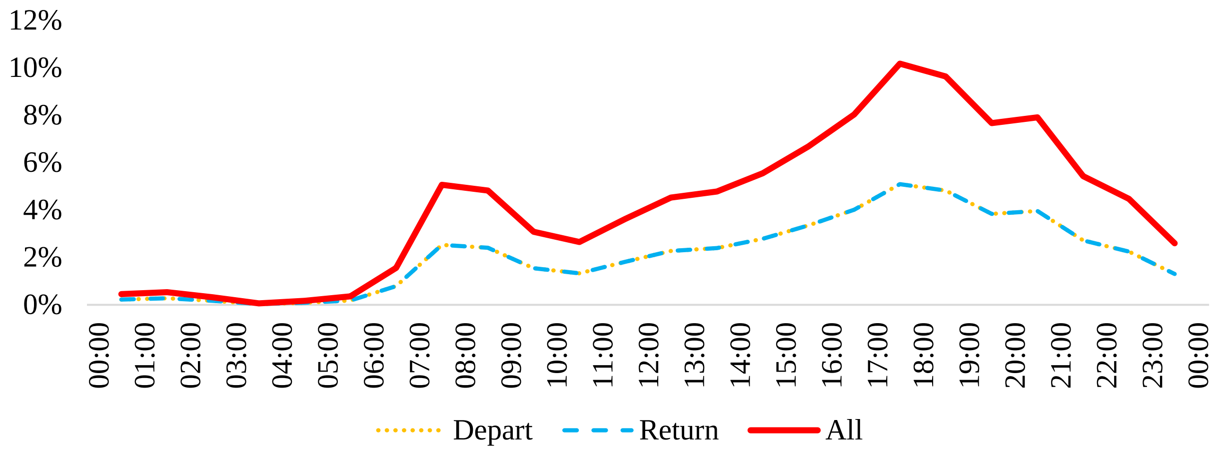


Figure 5.13 Time of Day and Directional Split for Outside Trips

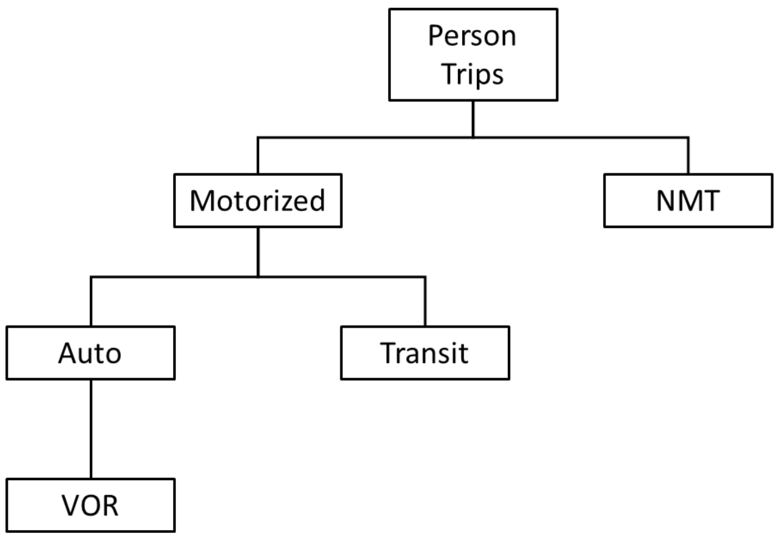


Thus the number of trips originated from one zone to another for each hour during the day can be calculated based on the percentages in time of day and directional split models built above. In other words, Daily Production-Attraction (P-A) Matrices developed through the trip generation and trip distribution models can be converted to O-D Matrices for each hour by using the time of day and directional split models.

5.5. Modal Split

Mode choice is the third major step in the traditional four-step travel demand model. In order to figure out how university students travel from their origins to destinations, we will develop two modal split models to separate non-motorized trips (NMT) and public transit trips from the overall person trips. An additional vehicle occupancy rate model will also be developed to convert the auto person trips into auto vehicle trips (see Figure 5.14). Considering the limited sample sizes, only one model will be built by using the combined data of all the universities surveyed for each model split model.

Figure 5.14 Modal Split Models



To split the non-motorized trips from the overall person trips, we can use Inverse Power Function to estimate the percentage of non-motorized trips based on the impedance:

$$\boldsymbol{NMT_{ij} = a \cdot d_{ij}^{-b}} \qquad \textit{(5-11)}$$

Where: $\boldsymbol{NMT_{ij}}$ = the percentage of NMT trips among all trips between zone $\boldsymbol{i}$ and zone $\boldsymbol{j}$
$\boldsymbol{d_{ij}}$= the impedance between zone $\boldsymbol{i}$ and zone $\boldsymbol{j}$
$\boldsymbol{a}$ and $\boldsymbol{b}$ are coefficients ($\boldsymbol{a}$>0; $\boldsymbol{b}$>0)

To separate the public transit trips from all the motorized trips, a linear regression model can be used to estimate the percentage of public transits of motorized trips based on the number of transit routes that serve the university campus:

$$\boldsymbol{Transit_{ij} = a \cdot N + b} \qquad \textit{(5-12)}$$

Where: $\boldsymbol{Transit_{ij}}$= the transit modal share of all motorized trips between zone $\boldsymbol{i}$ and zone $\boldsymbol{j}$
$\boldsymbol{N}$= the number of transit routes with bus stops within 1 mile from the campus
$\boldsymbol{a}$ and $\boldsymbol{b}$ are coefficients

To convert the auto person trips into auto vehicle trips, we can divide the auto person trips by the vehicle occupancy rates, which may vary from hour to hour. The ratios can be calculated based on the observed data from all the six universities surveyed.

5.5.1. On-Campus Student Crossing Trip (On-Crossing)

Table 5.18 summarizes the number of trip samples and the shares for each of the modes for on-campus student crossing trips across all the six university campuses.

Table 5.18 Weighted Modal Shares for On-Crossing Trips

University	Number of Trip Samples	Drive Alone	Shared Ride	Public Transit	Bicycle	Walk	Other
NCSU	128	19%	45%	13%	2%	21%	0%
UNCG	112	29%	32%	5%	2%	31%	0%
ASU	189	6%	22%	14%	0%	59%	0%
FSU	32	34%	41%	16%	0%	9%	0%
UNCW	323	46%	48%	1%	3%	2%	0%
UNCC	229	47%	42%	2%	0%	9%	0%
Total	1,013	24%	35%	9%	1%	31%	0%

Non-Motorized Modal Split

In order to figure out the numbers of non-motorized trips for on-crossing trips in each hour of the day, we can estimate the percentages of NMT trips based on the observed travel survey data from the six universities by using the Inverse Power Function which is a function of the network distances to campus central TAZs:

$$NMT_{cj} = a \cdot d_{cj}^{-b} \qquad \textit{(5-13)}$$

Where: NMT_{cj} = the share of NMT for trips between the campus zone and zone j
d_{cj}= the network distance from the campus central TAZ to non-campus zone j

To calculate the coefficients of the Inverse Power Functions for the NMT mode shares directly through linear regression models, we can rewrite the Inverse Power Function as:

$$ln(NMT_{cj}) = ln(a \cdot d_{cj}^{-b}) = ln(a) - b \cdot ln(d_{cj}) \qquad \textit{(5-14)}$$

Where: a= $e^{constant}$
b= negative of the coefficient for $ln(d_{cj})$

Figure 5.15 Observed NMT Modal Shares and Inverse Power Model for On-Crossing Trips

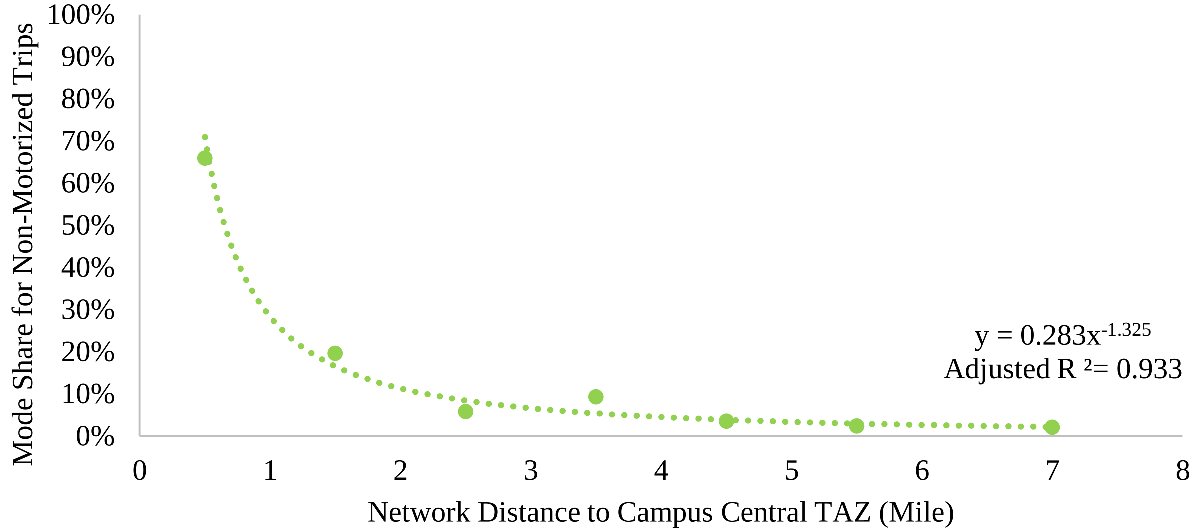


Figure 5.15 shows the observed percentages for non-motorized trips as well as the modeled NMT mode shares for on-crossing trips based on the Inverse Power Function developed for the combined data from all the six universities, which is:

$$\boldsymbol{NMT_{On-Crossing} = 0.283 \cdot d_{cj}^{-1.325}} \qquad \textbf{\textit{(5-15)}}$$

Thus, the numbers of non-motorized on-crossing trips in each hour between the campus zones and the non-campus zones can be calculated by multiplying the NMT modal shares for on-crossing trips which are based on Equation 5-15 to the total numbers of on-crossing trips distributed between zones in each time period which are obtained from the trip generation, trip distribution, time of day and directional split models in section 5.2.2, section 5.3.1 and section 1.1.

Public Transit Modal Split

With the non-motorized modal split models above, we can calculate the numbers of motorized on-crossing trips in each time period. To figure out the numbers of public transit trips, we can estimate the percentages of public transit trips among motorized on-crossing trips by using linear regression models with the number of transit routes serving the university campus as the independent variable based on the observed data and local transit networks.

Figure 5.16 Observed Transit Modal Shares and Linear Regression Model for On-Crossing Trips

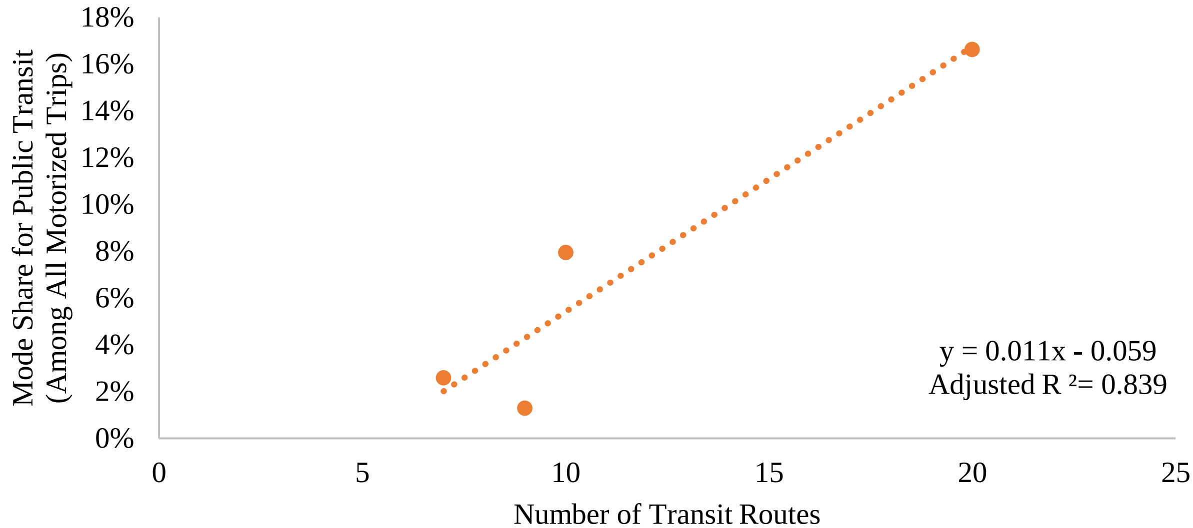


Figure 5.16 shows the observed mode shares for public transit among all motorized on-crossing trips as well as the linear regression model. Generally, the more transit routes are serving the university campuses, the higher the percentages for public transit will be. The linear regression function of public transit modal split model for on-crossing trips is:

$$\boldsymbol{Transit_{on-crossing} = 0.011 \cdot N - 0.059} \qquad \textbf{(5-16)}$$

Thus, we can calculate the numbers of on-crossing trips made by public transit for each time period by multiplying the mode shares for public transit based on Equation 5-16 to the numbers of motorized on-crossing trips from the non-motorized split models.

Vehicle Occupancy Rate

With the non-motorized and public transit modal split models above, we can obtain the on-crossing person trips that are made by automobile for each hour of the day. To figure out the numbers of on-crossing auto vehicle trips, we need to estimate the average vehicle occupancy rates based on the observed travel survey data, which may vary by the time of day.

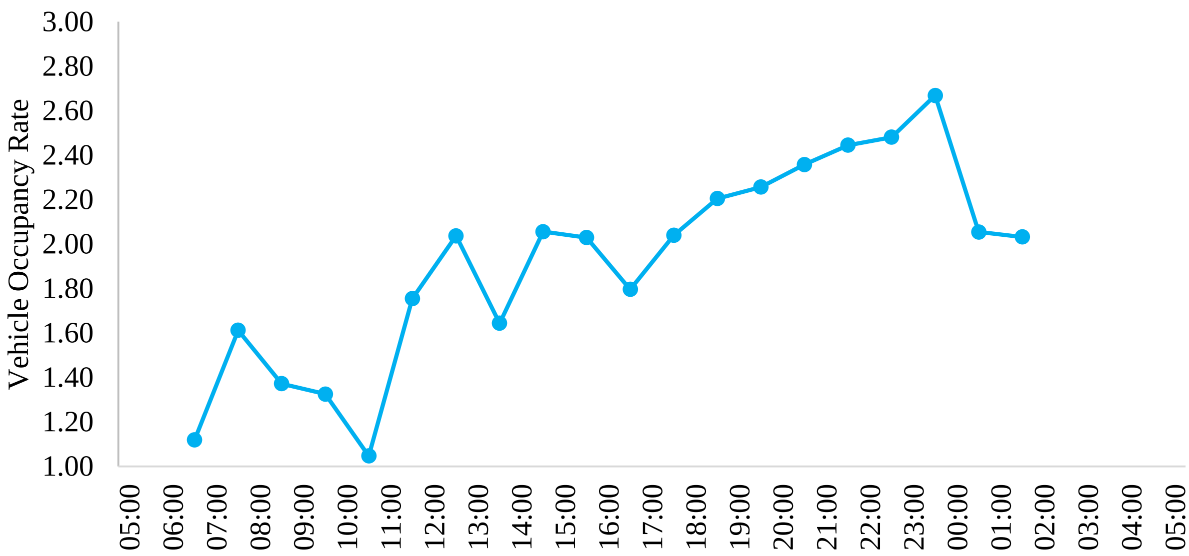
Table 5.19 and Figure 5.17 below show the number of auto trip samples and the average vehicle occupancy rates by time of day for the combination of the six universities. Due to the small sample sizes, some hours do not have reliable observations to estimate the vehicle occupancy rates.

Thus, the on-crossing vehicle trips between zones for each time period can be calculated by dividing the on-crossing auto person trips by the average vehicle occupancy rates in Table 5.19.

Table 5.19 Weighted Average Vehicle Occupancy Rates by Time of Day for On-Crossing Trips

Time of Day	Number of Auto Trip Samples	Weighted Average Vehicle Occupancy Rate
00:00-01:00	6	2.05
01:00-02:00	9	2.03
02:00-03:00	3	-
03:00-04:00	0	-
04:00-05:00	0	-
05:00-06:00	2	-
06:00-07:00	10	1.12
07:00-08:00	12	1.61
08:00-09:00	15	1.37
09:00-10:00	7	1.32
10:00-11:00	12	1.05
11:00-12:00	18	1.75
12:00-13:00	40	2.04
13:00-14:00	35	1.64
14:00-15:00	37	2.06
15:00-16:00	59	2.03
16:00-17:00	62	1.80
17:00-18:00	69	2.04
18:00-19:00	74	2.20
19:00-20:00	73	2.26
20:00-21:00	71	2.36
21:00-22:00	50	2.45
22:00-23:00	42	2.48
23:00-24:00	29	2.67
Total	735	2.11

Figure 5.17 Weighted Average Vehicle Occupancy Rates by Time of Day for On-Crosssing Trips



5.5.2. Off-Campus Student University-Based Home Crossing Trip (Off-1)

Table 5.20 summarizes the number of trip samples and the shares for each of the modes for off-campus student university-based home crossing trips across all the six university campuses.

Table 5.20 Weighted Modal Shares for Off-1 Trips

University	Number of Trip Samples	Drive Alone	Shared Ride	Public Transit	Bicycle	Walk	Other
NCSU	338	41%	7%	30%	1%	19%	1%
UNCG	369	43%	14%	9%	4%	28%	2%
ASU	310	28%	11%	41%	0%	19%	1%
FSU	179	86%	12%	2%	0%	0%	0%
UNCW	875	52%	10%	11%	14%	13%	0%
UNCC	1,519	68%	10%	5%	4%	13%	0%
Total	3,590	48%	10%	20%	4%	17%	1%

Non-Motorized Modal Split

Similar to the procedures for on-crossing trips, an Inverse Power Function is developed to estimate the percentages of non-motorized trips for off-1 trips in each hour of the day based on the observed travel survey data from the six universities.

Figure 5.18 Observed NMT Modal Shares and Inverse Power Model for Off-1 Trips

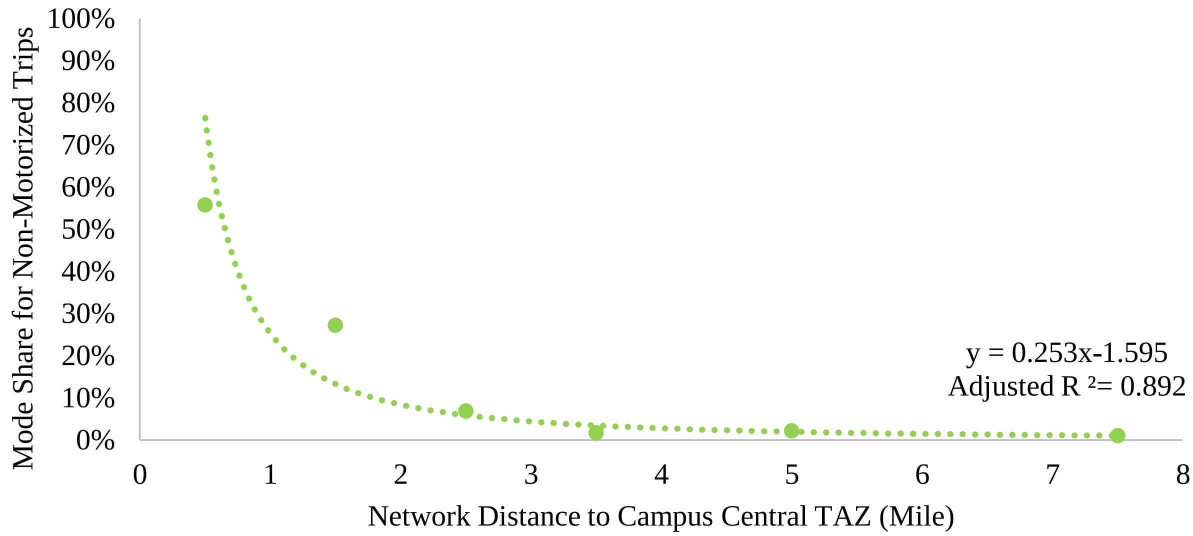


Figure 5.18 shows the observed percentages for non-motorized trips as well as the modeled NMT mode shares for off-1 trips based on the Inverse Power Function developed for the combined data from all the six universities, which is:

$$NMT_{Off-1} = 0.253 \cdot d_{cj}^{-1.595} \qquad (5\text{-}17)$$

Thus, the numbers of non-motorized off-1 trips in each hour between the campus zones and the non-campus zones can be calculated by multiplying the NMT modal shares for off-1 trips which are based on Equation 5-17 to the total numbers of off-1 trips distributed between zones in each time period which are obtained from the trip generation, trip distribution, time of day and directional split models in section 5.2.2, section 5.3.1 and section 1.1.

Public Transit Modal Split

Similar to the procedures for on-crossing trips, a linear regression model is developed to estimate the percentages of public transit trips among motorized off-1 trips based on the observed data and local transit networks.

Figure 5.19 Observed Transit Modal Shares and Linear Regression Model for Off-1 Trips

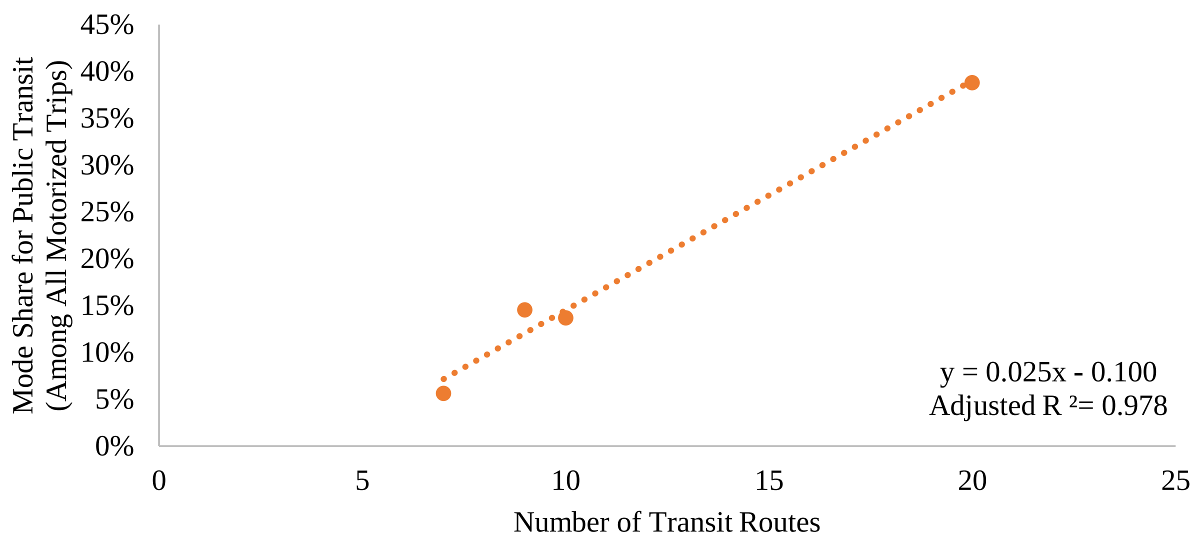


Figure 5.19 shows the observed mode shares for public transit among all motorized off-1 trips as well as the linear regression model, which is:

$$Transit_{off-1} = 0.025 \cdot N - 0.100 \qquad (5\text{-}18)$$

Thus, we can calculate the numbers of off-1 trips made by public transit for each time period by multiplying the mode shares for public transit based on Equation 5-18 to the numbers of motorized off-1 trips from the non-motorized split models.

Vehicle Occupancy Rate

With the non-motorized and public transit modal split models above, we can obtain the off-1 person trips that are made by automobile for each hour of the day. To figure out the numbers of off-1 vehicle trips, we need to estimate the average vehicle occupancy rates based on the observed travel survey data, which may vary by the time of day.

Table 5.21 Weighted Average Vehicle Occupancy Rates by Time of Day for Off-1 Trips

Time of Day	Number of Auto Trip Samples	Weighted Average Vehicle Occupancy Rate
00:00-01:00	12	1.63
01:00-02:00	8	1.72
02:00-03:00	5	-
03:00-04:00	0	-
04:00-05:00	3	-
05:00-06:00	12	1.05
06:00-07:00	32	1.27
07:00-08:00	204	1.18
08:00-09:00	227	1.20
09:00-10:00	213	1.18
10:00-11:00	192	1.14
11:00-12:00	115	1.22
12:00-13:00	139	1.14
13:00-14:00	148	1.12
14:00-15:00	90	1.12
15:00-16:00	166	1.43
16:00-17:00	134	1.22
17:00-18:00	173	1.25
18:00-19:00	135	1.22
19:00-20:00	97	1.32
20:00-21:00	117	1.32
21:00-22:00	109	1.40
22:00-23:00	39	1.66
23:00-24:00	38	1.16
Total	2,405	1.24

Figure 5.20 Weighted Average Vehicle Occupancy Rates by Time of Day for Off-1 Trips

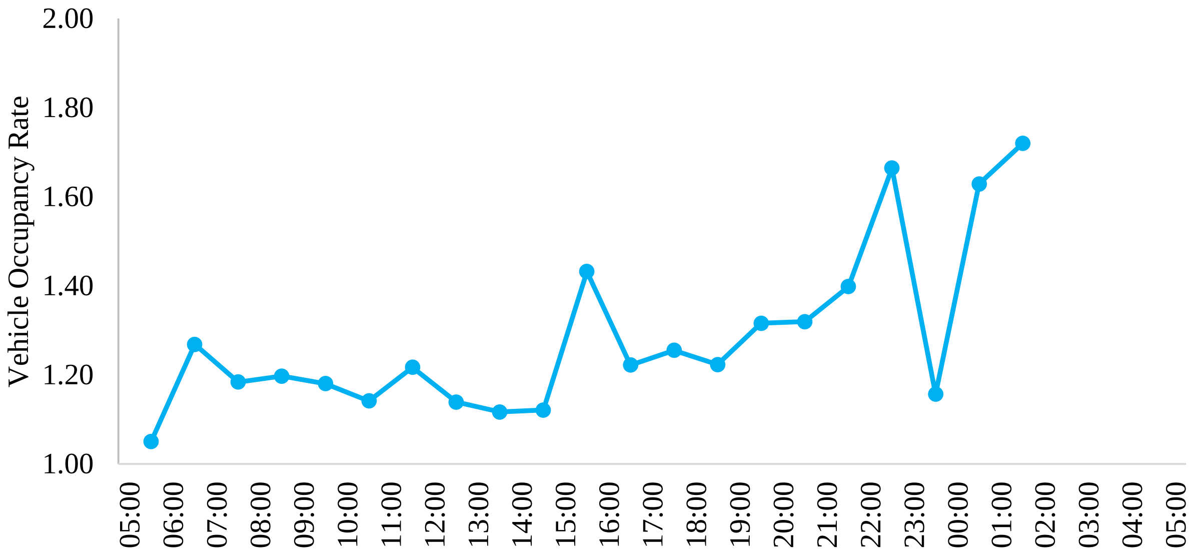


Table 5.21 and Figure 5.20 above illustrate the number of auto trip samples as well as the average vehicle occupancy rates by time of day for the combination of the six universities. Due

to the small sample sizes, some hours do not have reliable observations to estimate the vehicle occupancy rates.

Thus, the off-1 vehicle trips between zones for each time period can be calculated by dividing the off-1 auto person trips by the average vehicle occupancy rates in Table 5.21.

5.5.3. Off-Campus University-Based Non-Home Crossing Trip (Off-3)

Table 5.22 summarizes the number of trip samples and the shares for each of the modes for off-campus student university-based non-home crossing trips across all the six university campuses.

Table 5.22 Weighted Modal Shares for Off-1 Trips

University	Number of Trip Samples	Drive Alone	Shared Ride	Public Transit	Bicycle	Walk	Other
NCSU	132	48%	9%	16%	5%	22%	0%
UNCG	194	52%	28%	9%	0%	9%	2%
ASU	129	35%	20%	16%	1%	25%	3%
FSU	148	89%	9%	1%	0%	0%	2%
UNCW	330	68%	19%	8%	1%	4%	0%
UNCC	677	74%	15%	3%	1%	7%	1%
Total	1,610	58%	16%	10%	2%	13%	1%

Non-Motorized Modal Split

Similar to the procedures for on-crossing trips, an Inverse Power Function is developed to estimate the percentages of non-motorized trips for off-1 trips in each hour of the day based on the observed travel survey data from the six universities.

Figure 5.21 Observed NMT Modal Shares and Inverse Power Model for Off-3 Trips

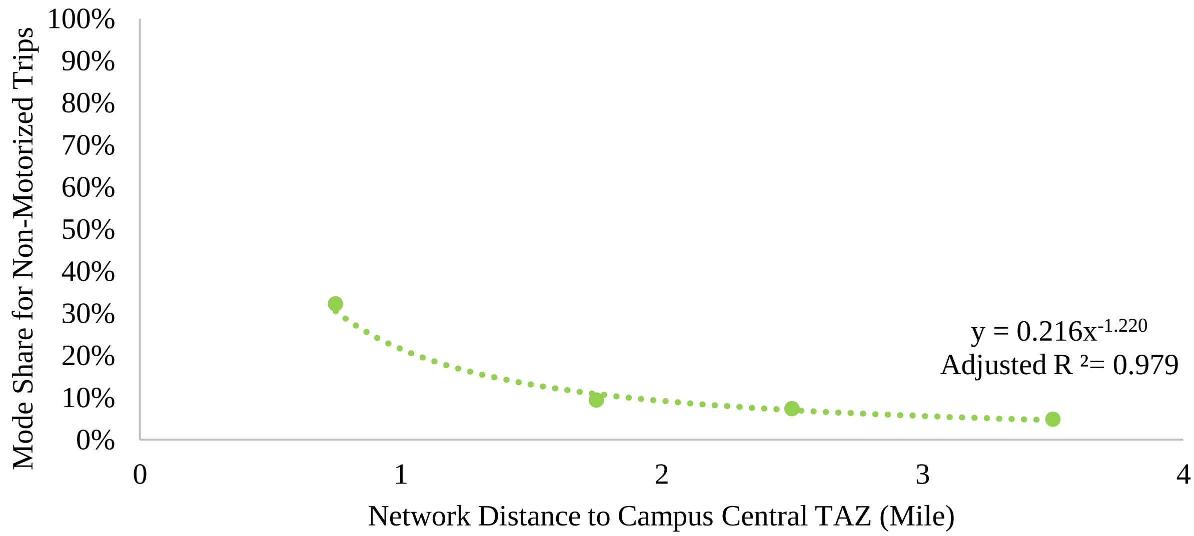


Figure 5.21 shows the observed percentages for non-motorized trips as well as the modeled NMT mode shares for off-3 trips based on the Inverse Power Function developed for the combined data from all the six universities, which is:

$$\boldsymbol{NMT_{Off-3} = 0.216 \cdot d_{cj}^{-1.220}} \qquad \textit{(5-19)}$$

Thus, the numbers of non-motorized off-3 trips in each hour between the campus zones and the non-campus zones can be calculated by multiplying the NMT modal shares for off-3 trips which are based on Equation 5-19 to the total numbers of off-3 trips distributed between zones in each time period which are obtained from the trip generation, trip distribution, time of day and directional split models in section 5.2.2, section 5.3.1 and section 1.1.

Public Transit Modal Split

Similar to the procedures for on-crossing trips, a linear regression model is developed to estimate the percentages of public transit trips among motorized off-3 trips based on the observed data and local transit networks.

Figure 5.22 Observed Transit Modal Shares and Linear Regression Model for Off-3 Trips

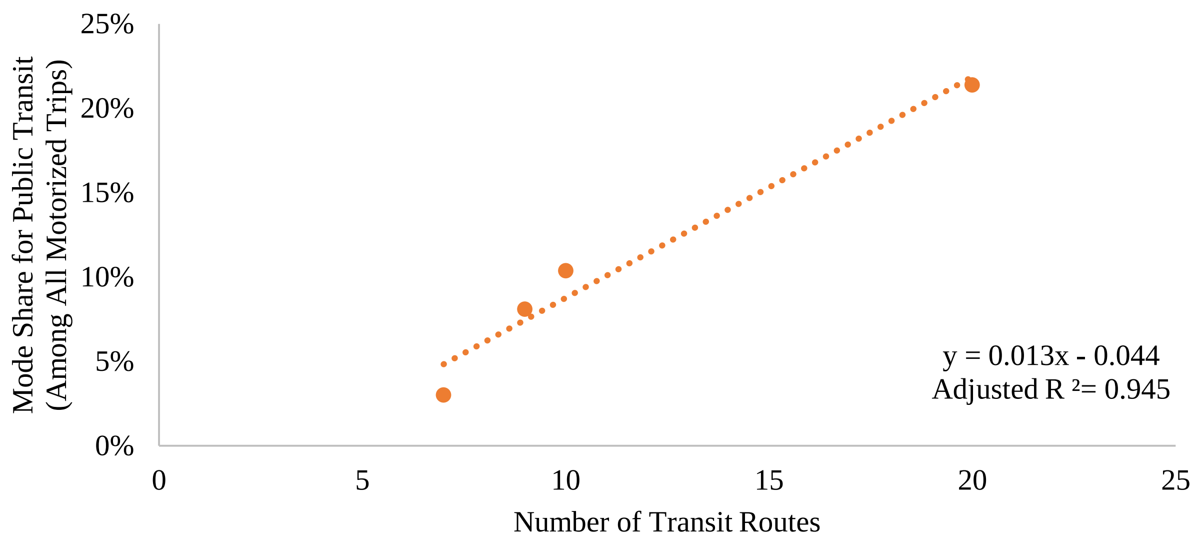


Figure 5.22 shows the observed mode shares for public transit among all motorized off-3 trips as well as the linear regression model, which is:

$$\boldsymbol{Transit_{Off-3} = 0.013 \cdot N - 0.044} \qquad \textit{(5-20)}$$

Thus, we can calculate the numbers of off-3 trips made by public transit for each time period by multiplying the mode shares for public transit based on Equation 5-20 to the numbers of motorized off-3 trips from the non-motorized split models.

Vehicle Occupancy Rate

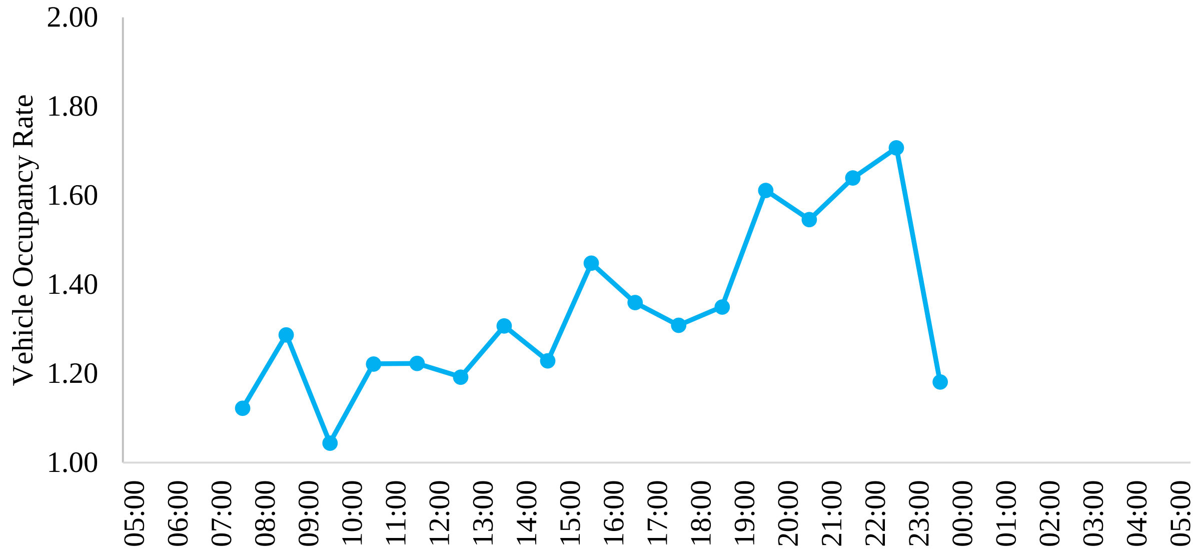
With the non-motorized and public transit modal split models above, we can obtain the off-3 person trips that are made by automobile for each hour of the day. To figure out the numbers of off-3 vehicle trips, we need to estimate the average vehicle occupancy rates based on the observed travel survey data that may vary by the time of day.

Table 5.23 and Figure 5.23 below illustrate the number of auto trip samples as well as the average vehicle occupancy rates by time of day for the combination of the six universities. Due to the small sample sizes, some hours do not have reliable observations to estimate the vehicle occupancy rates.

Table 5.23 Weighted Average Vehicle Occupancy Rates by Time of Day for Off-3 Trips

Time of Day	Number of Auto Trip Samples	Weighted Average Vehicle Occupancy Rate
00:00-01:00	0	-
01:00-02:00	1	-
02:00-03:00	1	-
03:00-04:00	2	-
04:00-05:00	0	-
05:00-06:00	3	-
06:00-07:00	5	-
07:00-08:00	27	1.12
08:00-09:00	44	1.29
09:00-10:00	58	1.04
10:00-11:00	63	1.22
11:00-12:00	93	1.22
12:00-13:00	140	1.19
13:00-14:00	132	1.31
14:00-15:00	107	1.23
15:00-16:00	150	1.45
16:00-17:00	112	1.36
17:00-18:00	149	1.31
18:00-19:00	91	1.35
19:00-20:00	53	1.61
20:00-21:00	56	1.55
21:00-22:00	35	1.64
22:00-23:00	10	1.71
23:00-24:00	8	1.18
Total	1,340	1.32

Figure 5.23 Weighted Average Vehicle Occupancy Rates by Time of Day for Off-3 Trips



Thus, the off-3 vehicle trips between zones for each time period can be calculated by dividing the off-3 auto person trips by the average vehicle occupancy rates in Table 5.23.

5.5.4. Outside Trip

Table 5.24 summarizes the number of trip samples and the shares for each of the modes for outside trips across all the six university campuses.

Table 5.24 Weighted Modal Shares for Outside Trips

University	Number of Trip Samples	Drive Alone	Shared Ride	Public Transit	Bicycle	Walk	Other
NCSU	324	67%	23%	2%	7%	1%	0%
UNCG	604	59%	34%	1%	5%	0%	1%
ASU	251	65%	25%	2%	7%	0%	1%
FSU	364	76%	21%	2%	1%	0%	0%
UNCW	1,004	68%	27%	1%	3%	1%	1%
UNCC	2,243	74%	23%	1%	2%	1%	0%
Total	4,790	68%	25%	1%	4%	1%	1%

Non-Motorized Modal Split

Similar to the procedures for on-crossing trips, an Inverse Power Function is developed to estimate the percentages of non-motorized trips for outside trips in each hour of the day based on the observed travel survey data from the six universities. However, since neither ends of the outside trips are within the campus boundaries, the impedances in the Inverse Power Function will be the network distances between the origin TAZs and destination TAZs instead of the network distances to campus central TAZs.

Figure 5.24 Observed NMT Modal Shares and Inverse Power Model for Outside Trips

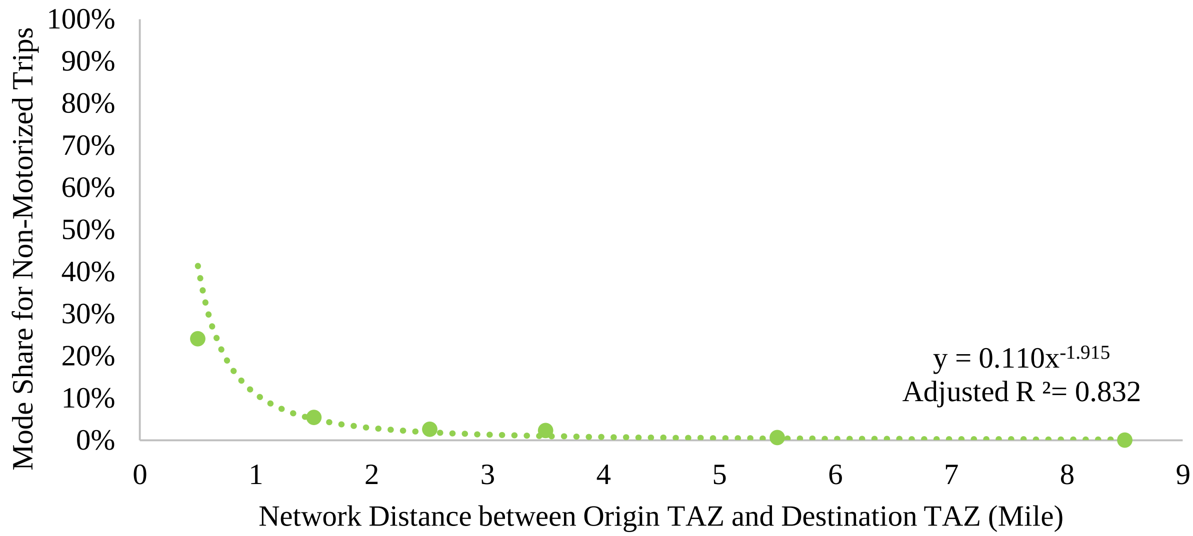


Figure 5.24 shows the observed percentages for non-motorized trips as well as the modeled NMT mode shares for outside trips based on the Inverse Power Function developed for the combined data from all the six universities, which is:

$$\boldsymbol{NMT_{Outside} = 0.110 \cdot d_{ij}^{-1.915}} \qquad \textit{(5-21)}$$

Thus, the numbers of non-motorized outside trips in each hour between the origin TAZs and destination TAZs can be calculated by multiplying the NMT modal shares for outside trips which are based on Equation 5-21 to the total numbers of outside trips distributed between zones in each time period which are obtained from the trip generation, trip distribution, time of day and directional split models in section 5.2.2, section 5.3.1 and section 1.1.

Public Transit Modal Split

For outside trips, neither of the trip ends are in the campus zones, so it is not proper to use the numbers of transit routes that serve the university campuses to estimate the mode shares for public transit. According to Table 5.24, the percentages of outside trips that are made by transit are rather small. Therefore, we will use simple factors obtained from the observed travel survey data to split the public transit trips from the motorized outside trips.

Table 5.25 lists the public transit mode shares among motorized outside trips for each of the six universities as well as the combined data.

Table 5.25 Weighted Public Transit Modal Shares for Motorized Outside Trips

University	Number of Motorized Trip Samples	Weighted Percentage for Public Transit
NCSU	290	2.06%
UNCG	564	0.77%
ASU	230	2.07%
FSU	357	1.52%
UNCW	958	0.80%
UNCC	2,170	0.78%
All	4,569	1.25%

Thus, we can calculate the numbers of outside trips made by public transit for each time period by multiplying the selected mode shares for public transit in Table 5.25 to the numbers of motorized outside trips from the non-motorized split models.

Vehicle Occupancy Rate

With the non-motorized and public transit modal split models above, we can obtain the outside person trips that are made by automobiles for each hour of the day. To figure out the numbers of outside vehicle trips, we can estimate the average vehicle occupancy rates based on the observed travel survey data, which may vary by the time of day.

Table 5.26 Weighted Average Vehicle Occupancy Rates by Time of Day for Outside Trips

Time of Day	Number of Auto Trip Samples	Weighted Average Vehicle Occupancy Rate
00:00-01:00	24	1.51
01:00-02:00	24	1.31
02:00-03:00	16	-
03:00-04:00	3	-
04:00-05:00	7	-
05:00-06:00	20	1.12
06:00-07:00	92	1.13
07:00-08:00	243	1.11
08:00-09:00	212	1.12
09:00-10:00	150	1.11
10:00-11:00	139	1.20
11:00-12:00	155	1.27
12:00-13:00	215	1.34
13:00-14:00	210	1.27
14:00-15:00	242	1.32
15:00-16:00	279	1.26
16:00-17:00	357	1.39
17:00-18:00	455	1.46
18:00-19:00	434	1.54
19:00-20:00	336	1.58
20:00-21:00	351	1.57
21:00-22:00	275	1.48
22:00-23:00	174	1.60
23:00-24:00	105	1.40
Total	4,518	1.39

Figure 5.25 Weighted Average Vehicle Occuppancy Rates by Time of Day for Outside Trips

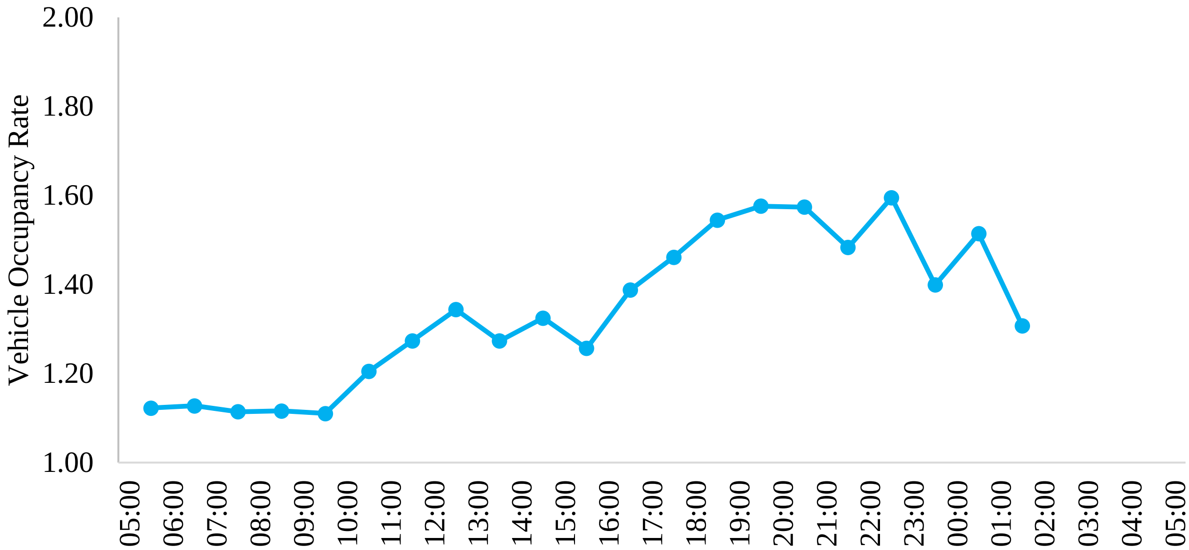


Table 5.26 and Figure 5.23 above illustrate the number of auto trip samples as well as the average vehicle occupancy rates by time of day for the combination of the six universities. Due to the small sample sizes, some hours do not have reliable observations to estimate the vehicle occupancy rates.

Thus, the outside vehicle trips between zones for each time period can be calculated by dividing the outside auto trips by the average vehicle occupancy rates in Table 5.26.

6. Conclusion

6.1. Major Findings

The average daily trip rate of university students in the six campuses surveyed is 5.34 trips/day. On-campus students make more trips than off-campus students but most of them are within the campus. Full-time students have higher trip rates than part-time students and most of them are within or crossing the campus boundary. Graduate students generate fewer trips than undergraduate students but have more trips made outside the campus. Students with cars make fewer trips than those without cars but have higher rates for trips crossing the campus boundary or outside the campus. Whether a university student is living on campus is a significant and the most important factor for the differences in trip rate.

The average trip distance of trips made by university students in all the six campuses surveyed is 3.55 miles and the average travel time is 12.44 minutes. On-campus students, full-time students, undergraduate students, unemployed students, students without cars and students who have no parking permits make shorter trips in terms of both trip distance and travel time. Within trips are shorter in both distance and travel time than the other trips. Crossing trips are shorter than outside trips in distance, but longer in travel time. Drive alone trips are longest in trip distance and fastest in average speed while public transit trips take longest travel time.

Most of the universities follow the similar time-of-day patterns. Trips start increasing at 7 am and the AM peak falls between 9 am to 10 am. The peak hours of the whole day are identified between 12pm and 2 pm. The PM peak may occur either between 3 pm and 4 pm or between 5 pm and 6 pm.

On-campus students choose to walk most while more than half of the off-campus students' trips are done by auto vehicles. Full-time students are in favor of both driving and walking while part-time students like driving alone. Graduate students drive more while undergraduate students prefer walking more than driving alone. Employed students would like to drive while students who are not employed prefer walking more. Students with cars drive more while those who do not have cars choose walking most. More than half of the trips generated by students who have parking permits are made by driving alone. University students without parking permits are most likely to walk.

6.2. Model Applications

The university student travel demand model developed in this research project can be incorporated into the current regional travel demand models in North Carolina to better model the trips made by university students. Based on the conventional four-step travel demand model, the university student trips will be modeled separately from the trips made by the general population until the traffic assignment.

The first step of modeling the university student trips is to identify the university students among the general population within the region. The total enrollments and the numbers of students living on campus and off campus are usually collected by the universities and available on their official websites. If the university campus covers several TAZs, the on-campus students will be assigned to each zone based on the locations of the dormitories. Otherwise, all the on-campus students will be added to the only campus TAZ. If the addresses of the off-campus homes can be obtained, then off-campus students can be easily assigned to the TAZs that their homes locate. If the addresses are not available, off-campus students can be allocated based on the information of the distances from off-campus homes to university campus boundaries in section 4.1.2, combined with the socio-economic data for each zone. After identifying all the university students in each TAZ, we need to deduct the university students from the general population to avoid double counting.

The trip generation models developed in section 5.2 can be used to calculate the trips of each category generated in each zone. Then we can use the trip distribution models in section 5.3 to distribute those trips and develop Daily P-A Matrices showing how the university student trips are produced by one zone and attracted to another. The time of day and directional split models in section 5.4 can then convert the Daily P-A Matrices into O-D Matrices for each hour of the day. Non-motorized modal split models and public transit modal split models in section 5.5 can help tease out the auto person trips from all of the university student trips. The vehicle occupancy rates also developed in section 5.5 which are based on time of day can convert the auto person trips into auto vehicle trips. Thus, O-D Matrices for university student auto vehicle trips for each hour can be obtained through all the steps above. The matrices can be aggregated based on the definitions of time periods in the local travel demand models. The university student O-D Matrices will finally be added to the O-D Matrices of auto vehicle trips made by the general population for each time period, which will be used to assign the trips to the regional road networks.

6.3. Limitations

Several limitations of the research project should draw the attentions. The total number of 3,397 usable personal diaries for six university campuses is a decent sample size. However, the samples are not evenly distributed among different universities. FSU has only 224 person samples and 1,074 trip samples, making the confidence intervals of trip rates too wide and no satisfactory trip distribution models can be developed for on-crossing, off-3 and outside trips of FSU students. Considering that FSU has a unique small campus setting, it is unfortunate that no complete model for all trip categories can be built for FSU as a model for universities with small campus sizes in the urban areas.

Another limitation is that a parametric approach is used for modal split models instead of the discrete choice model, which is the common practice for the mode choice model in the four-step travel demand model. The reason for using the current approach is that only four of the six universities surveyed have provided the transit networks and the transit trip samples are too small to develop satisfactory multinomial or nested logit models for modal split models for each trip category. The mode choice model can be improved if we have larger sample sizes.

Models for outside trips have been developed for the purpose of completeness. However, trips for different purposes and trips made by students of different residential statuses are all modeled together due to the limited sample sizes. Better models can be built if we have more samples for outside trips.

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