UTILIZING STUDENT SCHEDULE DATA
TO DEVELOP TRAVEL MATRICES
FOR TRANSIT AND PEDESTRIAN TRAVEL DEMAND MODELS

by

Benjamin S. Fisher

A thesis submitted to the Faculty of the University of Delaware in partial fulfillment of the requirements for the degree of Master of Civil Engineering

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ABSTRACT

Personal rapid transit (PRT) is one example of an automated public transit system used for distributing small groups of individuals throughout a defined area. When used in combination with the four-step travel demand modeling process, the origin-destination (OD) matrix developed in the research provides the framework for examining the viability of implementing PRT service on a university campus. The methodology uses institutionally provided data to estimate demand for student trips throughout the workweek. Data includes student class schedules as well as the supply of on-campus residences and parking spaces.

A case study is modeled around the student population attending the University of Delaware's Newark Campus, under the assumption of a fixed schedule for the duration of the semester. The case study operates using several assumptions: trips and events occur between fixed time intervals, all trips are conducted with the same degree of importance, and all trips are conducted in a similar manner regardless of surrounding conditions. Recommendations for future research include expansion of the population to include university faculty and staff, inclusion of nearby activities as potential trip locations, consideration of trip purpose, and integration with travel demand modeling software.

Chapter 1

INTRODUCTION

1.1 Problem Statement

Transportation planners apply travel demand models to aid in the prediction of the impacts regarding a proposed infrastructure or land use change. The four-step model is an example of a widely used model that uses the socioeconomic status of the encompassing region to calculate the demand for individuals to utilize transportation infrastructure. Within the four-step model, distinct steps occur: trip generation, trip distribution, mode choice and trip assignment. Trip generation is the most general process, defining the total number of journeys that will occur across the entire study area. Trip distribution builds upon this by assigning each trip a beginning and an end, creating a theoretical origin-destination matrix. Mode choice determines the method, or mode, of transportation by which each trip will be completed. Lastly, Trip assignment determines the exact route each trip will traverse, producing a path reflecting optimal usage. When analyzing the introduction of a transit system to a university campus, however, socioeconomic data is an unreliable source of determining trip frequency. One solution involves maintaining the existing process, which requires data collection using a local travel survey to replace socioeconomic information. A more feasible approach, however, involves replacing the trip generation and trip distribution steps with a preconstructed origin-destination (OD) matrix. This thesis analyzes known student locations to produce an exact OD matrix, and explains its integration with the four-step travel demand model.

1.2 Motivation

Among literature focusing on travel demand modeling, many methods have been developed to gather travel pattern information. Little research, however, has looked at the application of gathering data unique to a university setting.

1.3 Objectives

This analysis provides the framework necessary to accurately analyze the feasibility of operating a public transit system on a university campus. The primary objective of this research is to provide an alternative to using national data within a travel model's trip characteristic assumptions. The secondary objective of this research is to provide an example of using existing data to automatically construct a travel matrix, reducing the required resources.

1.4 Thesis Outline

Chapter 1 provides a brief overview of the paper, discussing the problem and the purpose of the solution. Chapter 2 introduces literature relevant to the issue, and discusses the problem in a historical context. Chapter 3 introduces the methodology followed. Chapter 4 introduces the case study of students attending the University of Delaware in Newark. Chapter 5 concludes the paper, providing a summary and recommendations for future research.

Chapter 2

LITERATURE REVIEW

2.1 Background

The literature review includes topics relevant to travel demand modeling, with a focus on methods used to construct a travel matrix. This review attempts to understand current practice and its processes, changes required to adapt this practice to the university environment, alternative methodologies developed for use outside the university environment, and examples of similar past studies.

2.1.1 Travel Demand Models

A travel demand model is a software program written to forecast long-term demand upon a transportation network. Depending on the desired detail level, two variants exist: activity-based modeling, which focuses on travel generated by an individual's desire to perform activities, and trip-based modeling, which focuses on the aggregated supply and demand for travel across the population (McNally, 2007). Due to the reduced amount of data needed to construct a trip-based model, many regional transportation models are based off a variant known as the four-step model. The four-step model consists of distinct processes: trip generation, trip distribution, mode choice and traffic assignment. The first step, trip generation, is the most comprehensive, determining the overall necessity for movement using the analysis of land-uses across the region (Martin et al., 1998). Trip distribution expands upon this by introducing individual trips, evaluating the ease of travel to define a beginning and an end (Martin et al. 1998). At this moment, the arrival and departure locations of every trip are consolidated into a table, known as the origin-destination (OD) matrix. The next step, mode choice, is the most relevant process to public transit agencies, because it determines the method by which each trip will be completed (Martin et al., 1998). The final process, traffic assignment, operates at the highest level of detail, specifying an exact route each trip will follow, which enables transportation planners to predict traffic volumes on individual roadway segments (Martin et al., 1998). Traffic assignment is important for validating the model, because traffic volumes predicted under existing conditions, or the base year, may be compared to observed traffic volumes.

2.1.2 Travel Surveys

National travel surveys are conducted to provide data to support the default assumptions made by trip-based models. Historically, two surveys were conducted: the Federal Highway Administration's Nationwide Personal Transportation Survey (NPTS), which targeted shorter trips conducted as part of a routine, and the Bureau of Transportation Statistics' American Travel Survey (ATS), which targeted long-distance trips related to special events (Collia et al., 2003). In 2001, both agencies collaborated to consolidate the NPTS and ATS into a new survey, known as the National Household Travel Survey (NHTS). The NHTS estimates travel patterns by collecting information regarding household and trip characteristics. Household characteristics include occupant information, such as the number of drivers, as well as their respective ages, incomes and genders (Collia et al., 2003). Likewise, trip characteristics include information about the journey, such as the transportation mode, travel time and purpose (Collia et al., 2003). The methodology followed by the NHTS involves contacting participants by telephone and asking them to record a travel diary for a specified trip day in the future (Collia et al., 2003; Stopher et al., 2007). Travel diaries are used to combat the disadvantages of requesting participants recall their trips; ideally they will be completed at the time of the trip.

2.1.3 Motivation

When discussing the application of trip-based travel demand modeling within a university context, scholars recognize the challenges with extrapolating national data. Two main issues result in incorrect travel assumptions among the university population: the underrepresentation of student survey responses relative to their proportion of the population, and the misinterpretation of the university environment when calculating trip frequency. The first issue, underrepresentation, is primarily caused by the challenges of contacting students who reside on campus. For example, many dormitory buildings no longer have landlines installed, which precludes students from participating in geographically targeted telephone surveys (Wang et al., 2012). The second issue, misinterpretation of the university environment, occurs because socioeconomic factors traditionally incorporated into models, such as household size, automobile ownership and household income, are ineffective when determining trip frequency on campus. Relative to their surroundings, universities often contain higher-density environments, encouraging individuals to travel using a variety of non-motorized transportation methods (Bustillos et al., 2011; Wang et al., 2012; Young et al., 2004). This distinction means that other factors, such as academic status or residential location, play a more significant role in determining travel habits. Therefore, to correctly model university-based travel, a unique methodology must be developed that considers both issues.

2.1.4 Alternative Methodologies

Methodologies have been developed to mitigate similar situations. Conducting a local travel survey or constructing an activity-based model are solutions, but these require a large amount of initial investment. The application of data already collected requires less overhead, and has been used in instances such as mobile phone and social media tracking. Using these processes, it is possible to determine trip characteristics regardless of the uniqueness of the study area.

2.1.4.1 Mobile Phones

One method that uses existing data to construct an origin-destination matrix involves the acquisition of mobile phone based location data. Service providers, to provide reliable service and comply with regulations requiring localized emergency service, continuously track an approximate location of handsets within their network (Caceres et al., 2007). This means that location data may be provided even when the user is not actively engaged with their phone, so long as a cell site is close enough to provide a signal. Additionally, the large market penetration of mobile phones allows for a sufficient sample size, encompassing a variety of travel patterns. The lack of accuracy, however, limits its use to trips conducted by automobile, since the location is limited to the service area of the cell site. Due to differing service demands, this distance may be anywhere between approximately 600 feet in the city to 12.5 miles in rural locations (Caceres et al., 2007). These limitations mean that this method is not an acceptable alternative for conducting surveys on a university campus.

2.1.4.2 Social Media

A second method incorporates spatial-temporal data shared on social media to develop traits for generalized travel habits. Along with social media's evolution, innovations have expanded the ability to gather location-based data, such as the user's endorsed sharing of time and location data through "check-in" opportunities at events, and the service provider's increased monitoring of location traces (Li et al., 2015). This means that while the metadata associated with social media posts, statuses and photos was traditionally limited to a timestamp, an increasing proportion are including an individual's location as well. This association of spatial-temporal data is significant because, contrary to methodologies associating data with an individual (such as national surveys or mobile phone data), social media information is consolidated and used to determine mobility based upon a location. Past studies have determined that social media changes across political boundaries, signifying that it may be used for travel estimation on a regional scale (Hawelka et al., 2014; Li et al. 2015). While this is useful for predicting commerce amongst cities or countries, the scope of this data precludes its application to a university campus.

2.2 Past Related Research

Past studies have been conducted proposing similar methodologies applied to the university setting. In 2001, a student travel survey was conducted at the University of North Carolina to aid in the development of an activity-based travel demand model. Additionally, in 2003, a unique travel demand model was developed by Kansas State University to understand the mobility impacts a personal rapid transit system would have on campus.

2.2.1 Student Activity Travel Survey

Recognizing the need to supplant generalized trip rates, the University of North Carolina commissioned a travel survey to better understand student travel patterns. One objective of this study was to support future development of an activity-based model, so a comprehensive questionnaire was developed that collected attributes relevant to educational status, residency type, travel mode used and trip purpose (Eom et al., 2009). Despite a difference in the targeted model, similarities exist when compared to the National Household Transportation Survey. For example, education status (enrollment in an undergraduate or graduate degree program) and residency type (housing arrangement in an on-campus or off-campus location) describe the individual making the trip, replacing traditional household characteristics (socioeconomic status). Likewise travel mode and trip purpose are the same descriptors collected nationally. Weaknesses of this methodology include the larger amount of resources, both temporal and financial, required to complete the study.

2.2.2 Kansas State University

Understanding the multimodality limitations of current travel demand models, Kansas State University and the Kansas Department of Transportation developed a unique campus-wide model. The model's primary objective was to use preexisting university data to understand the impacts of implementing a personal rapid transit (PRT) system on campus (Young et al., 2004). This was assessed by developing two iterations of the model: one reflecting existing conditions and the other showing a fully-operational PRT system. A limitation of this model involves its disregard for the operating components of the PRT system, considering its effects on mobility alone.

2.3 Summary of Relevant Research

Several methodologies have been developed similar to the proposed procedure, but each differs in a significant way. Table 1 summarizes each methodology and provides reasoning for its limitations with regard to university travel demand modeling.

Table 1: Summary of Relevant Methodologies

Methodology	Notable Difference
National Travel Survey	Provides general reference information for trip frequency; unsuitable for unique environments
Mobile Phones	Location limited to service area provided by cell tower; better scaled toward automobile use
Social Media	Necessary to consolidate individual data points; better scaled toward regional travel
Student Activity Travel Survey – University of North Carolina	Follows similar principle, but incorporated into activity-based model
Preexisting Information – Kansas State University	Most similar; considers mobility characteristics only

Chapter 3

METHODOLOGY

3.1 Introduction

The student origin-destination (OD) matrix forecasts travel demand on a university campus during class exchanges. The matrix is constructed using the Microsoft Excel software package, and is automated using scripts written with the Visual Basic for Applications extension.

3.2 Data Sources

Multiple information sources are used to verify trip accuracy, replacing the need for the trip generation and trip distribution steps within the four-step travel demand model. Sources include: a list of student class schedules (determining when and where students need to travel), an inventory of the housing stock (determining the amount and default locations of students living on-campus) and a record of parking availability (determining the default locations of students living off-campus). Data from each source was likely collected, compiled and maintained by the university, reducing the effort needed to generate trip values. Consolidation of these sources enables the production of daily travel itineraries, providing a close approximation of the volume of individuals traversing the campus. Each data source should be formatted into a spreadsheet to allow for necessary communication with programs written to construction the origin-destination matrix.

3.2.1 Student Class Schedules

The first constituent of the OD matrix creation process consists of student schedule data. A student's class roster induces travel, determining his or her need to leave their default location throughout the day. The exact content may vary, but information should be classifiable into three categories: student information, course information, and spatial and temporal information. First, student information includes statistics regarding the enrollee, such as ID number and degree program. To suppress privacy issues when distributing this data, the institution may remove personally identifiable characteristics, such as a student's name and address. Next, course information includes data relevant to the class and its content, such as the subject, instructor, catalog number, description and section number. Some information, such as section number, may be extraneous to smaller colleges, where multiple course instances are not offered. Lastly, spatial and temporal information includes data regarding meeting time and location, such as the start and end times, days occurring, building name and classroom number. When combined with the assumption that the singular travel purpose involves class attendance, this data may be used to determine either the origin or destination for each trip. The location of the other half of the trip, however, must be determined using additional information.

3.2.1.1 Preprocessing: Trip Chain

Since students might not have enough time to return home when classes are close together, a fourth information category may be developed: participation in a "trip chain". A trip chain introduces the concept of allowing students to travel directly between classes and is determined by analyzing the amount of free time between classes. To understand the applicability of a trip chain, however, a standard unit of measurement must be developed. Classes are rounded to the nearest half-hour to comply with travel matrix intervals, so classes occurring within half an hour of each other require participation in a trip chain. Trip chain participation should be recorded in Excel such that it can be referenced when constructing the OD matrix.

3.2.2 Residency Data

Latter components of the OD matrix creation process determine a student's default, or home location. Residency data, for example, examines dormitory occupancy to determine a student's ability to live on-campus or off-campus. Content should include an inventory of dormitory buildings, but may be limited to the total number of beds located in each, in which case data manipulation is required to assign students to unique locations.

3.2.2.1 Preprocessing: Dormitory Assignment

One challenge in determining a student's home location involves the limited knowledge shared regarding dormitory occupancy. If the housing assignments for students are unknown, residency may be approximated by referencing the student schedule information.

The first process involves the accurate distribution of on-campus housing availability throughout the student body. Assuming every student would consider residing on-campus, this is calculated by comparing the supply of beds to the student population. Each student is assigned a random number, correlating the result to the student proportion who may be accommodated by university housing. For example, if dormitories have the capacity to house 60% of students, numbers 1-60 might represent an on-campus residency, while numbers 61-100 could represent an off-campus residency. After specific students have been determined to live on-campus, a second step is required to resolve their unique building assignments.

The second process concerns properly distributing on-campus housing locations. Assuming each dormitory has the same entry requirements, this is calculated by comparing the relative supply of beds within individual buildings. Each student is again assigned a random number bounded by the total number of beds. In this instance, however, buildings are identified by their position in the cumulative total. For example, if Building A has 20 beds and Building B has 30 beds, numbers 1-20 correspond to living Building A, while numbers 21-50 correspond to living in Building B. This building assignment determines the default location of each on-campus student.

3.2.3 Parking Data

Parking data factors into the final component in the OD matrix creation process, and determines the default location of students living off-campus. Since the extent of the OD matrix considers on-campus travel only, parking stalls act as the home location for off-campus students. Comparable to the residency data, content should include an inventory of parking lots and the number of spaces in each, but may exclude the identity of permit holders.

3.2.3.1 Preprocessing: Stall Assignment

If no record of students assigned to individual parking lots exists, other factors may be introduced to increase the estimation accuracy. For example, students may not have the ability to procure permits for all lots. After exclusions have been determined, a similar process to the dormitory determination may be followed. Random numbers are assigned with the results correlated to the proportion of spaces provided in each lot.

3.3 Procedure

After the home locations have been determined for all students, it is possible to construct an OD matrix for any day of the semester. This process may be broken into three steps: determining the matrix properties, determining the time between classes and manipulation of the data to form the matrix.

3.3.1 Matrix Properties and Requirements

Since the origin-destination (OD) matrix captures travel occurring within a specific time interval, properties such as allotted travel time and travel frequency are integral to its ability to capture movement. Using this methodology, class attendance is the singular factor compelling trip occurrence, so the OD matrix needs to reflect trips taking place during class exchanges. This allows the first property, travel time allotted, to be calculated using the maximum travel time between a home and class location. Determination of travel frequency, however, requires an analysis for patterns within the university's class listing. For example, some universities operate under a schedule whereby classes alternate days throughout the week. To balance instruction time a connection is made between meeting frequency and meeting length, which allows courses meeting twice weekly to maintain a similar amount of instruction time as those meeting three days a week. Since schedules across weeks are consistent, a semester's travel demand may be represented using the class exchanges across a five-day period. Furthermore, if each class meets at least twice weekly, it is possible to construct matrices representing travel for two days.

3.3.2 Matrix Definition

An origin-destination matrix consists of a table representing travel between two locations. Each row represents an originating location, while each column represents a destination. Travel between an origin and destination is represented by the cross-section of the respective row and column. For example, Figure 1 displays a visual representation of travel between locations A, B, C and D. 13 trips travel from A to C, which is shown in the origin-destination matrix in Figure 2 by referencing the cross-section between row A and column C. One method used to verify the comprehensiveness of a matrix involves comparing the summation of all the rows (total departures) to the summation of all the columns (total arrivals).

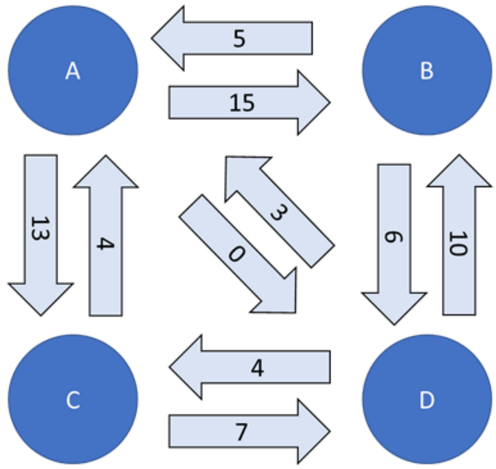

Figure 1: Example of Travel between Sites

	Destinations					
Origins		A	B	C	D	$\Sigma_{Departures}$
	A	0	15	13	0	28
	B	5	0	0	6	11
	C	4	0	0	7	11
	D	3	10	4	0	17
	$\Sigma_{Arrivals}$	12	25	17	13	67

Figure 2: Corresponding Origin-Destination Matrix

3.3.3 Matrix Construction

Several functions written in Microsoft's Visual Basic for Applications (VBA) software extension transform data from individual spreadsheets into the OD matrix. Necessary spreadsheets include student schedule data (including the determination of trip chain participation) and student housing data (including the student assignment to individual dormitory and parking locations). Functions calculate the pertinent travel demand by separating classes into four outcomes: no trip occurs (class occurs during the wrong day and/or time), a trip occurs from home to class (class occurs immediately after matrix and it is not part of a trip chain), a trip occurs from previous class to class (class occurs immediately after matrix and it is part of a trip chain), and a return trip occurs from class to home (class occurs immediately before matrix and it is not part of a trip chain). Table 2 presents a summary of all functions written while Appendix A explains each function's operation in detail. Figure 3 provides a visual representation of the program, clarifying each function's execution order.

Table 2: Summary of Functions Written

Function	Description
CheckClassDay	• Includes a loop to cycle through student class schedule spreadsheet • Ensures only classes occurring during specified travel day are represented
CheckBeginTime	• Subset of CheckClassDay • Ensures only classes beginning immediately after exchange time are represented
CheckEndTime	• Subset of CheckClassDay (occurs after failed instance of CheckBeginTime) • Ensures only classes ending immediately before exchange time are represented
CheckTripChain	• Subset of CheckBeginTime • Considers class participation in a trip chain
NoTripChain	• Subset of CheckBeginTime and CheckEndTime • Ensures class is excluded from participating in a trip chain
FindHomeLocation	• Includes a loop to cycle through student housing location spreadsheet • Determines default student location
PriorClassLocationOrigin	• Includes a loop to cycle through rows in OD matrix • Occurs when class after exchange time participates in trip chain • Matches location of prior class to appropriate row in OD matrix
HomeLocationOrigin	• Includes a loop to cycle through rows in OD matrix • Occurs when class after exchange time is not part of a trip chain • Matches home location to appropriate row in OD matrix

Table 2 continued

ClassLocationOrigin	• Includes a loop to cycle through rows in OD matrix • Occurs when class before exchange time necessitates a return trip • Matches location of class to appropriate row in OD matrix
ClassLocationDestination	• Includes a loop to cycle through columns in OD matrix • Occurs when student travels to class • Matches class location to appropriate column in OD matrix
HomeLocationDestination	• Includes a loop to cycle through columns in OD matrix • Occurs when student returns home from class • Matches home location to appropriate column in OD matrix

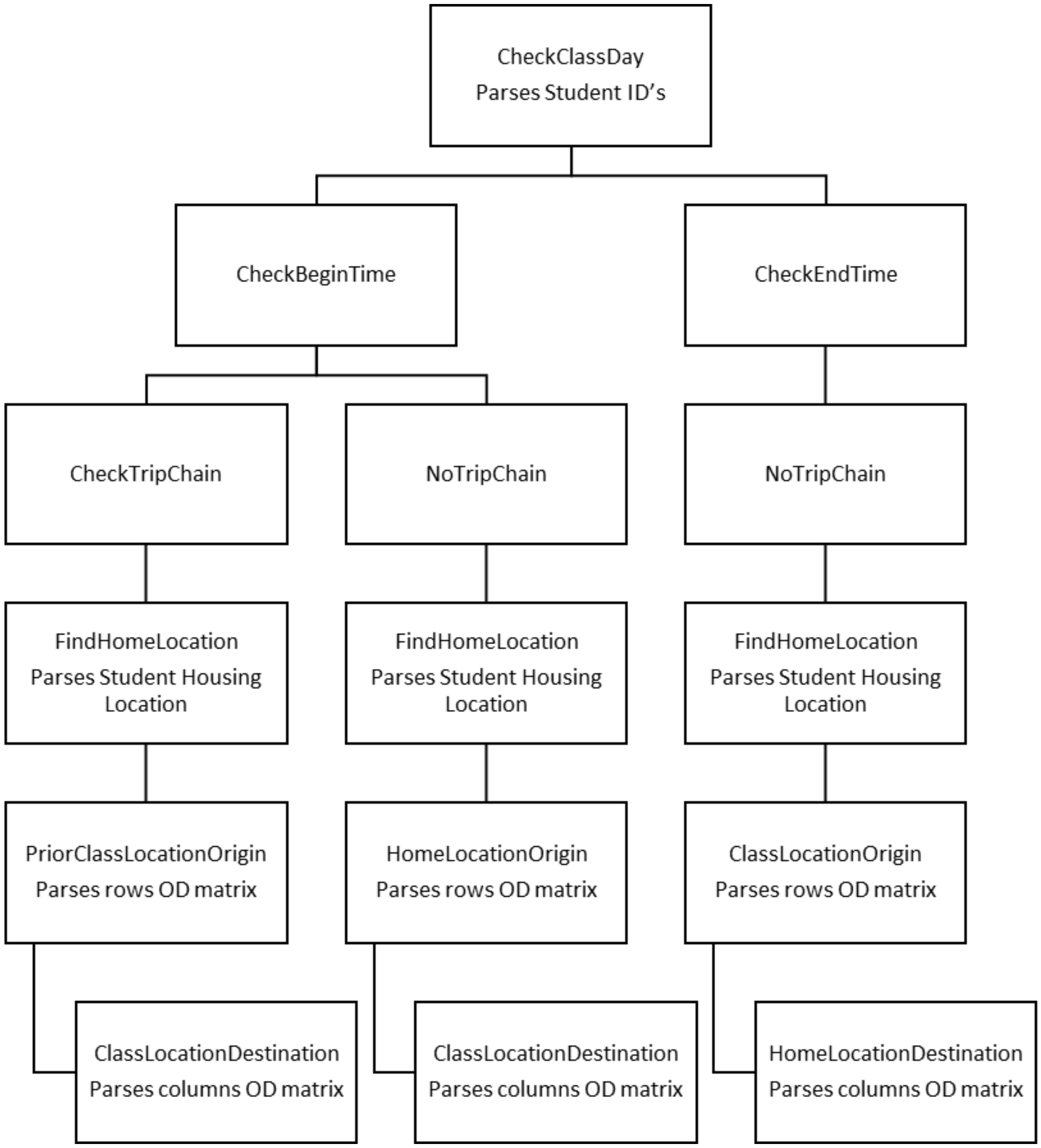

Figure 3: Visual Representation of Program Written

Chapter 4

CASE STUDY

4.1 University of Delaware

The University of Delaware is the largest educational institution within Delaware, and operates campuses in Wilmington, Newark, Dover, Georgetown and Lewes. The Newark Campus is the University's primary location, educating approximately 17,000 undergraduate students. Roughly 7,300 students (43%) choose to reside in a dormitory while most off-campus students are dispersed throughout Newark in smaller residencies. The study area is defined as the boundaries of the Newark campus (depicted in the central portion of Figure 4), and includes the dormitories of on-campus students while considering entry points used by off-campus students.

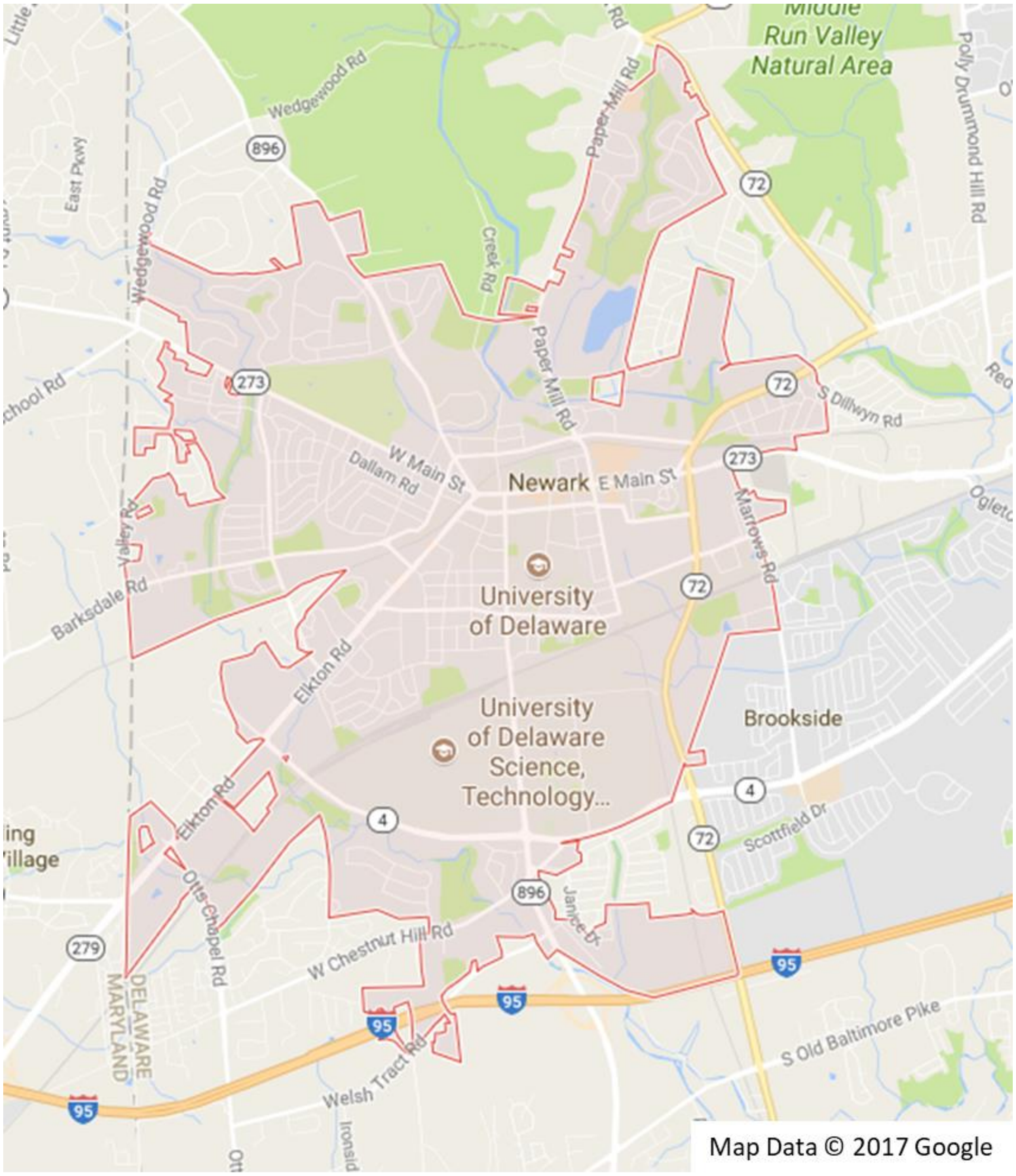

Figure 4: Newark City Limits (Google Inc., 2017)

4.1.1 Geography

According to the University's asset numbering scheme, the Newark Campus is divisible into several regions: North/Laird Campus, Central Campus, West Campus, East Campus and South Campus.

The northernmost area, Laird Campus, is bounded to the west by New London Road, and to the south by Main Street. It is the largest housing location for sophomores and upperclassmen, providing suite-style rooms and apartments that allow students to live independently while maintaining access to university resources. Amenities such as a dining hall, convenience store and recreational activities are provided locally, but most activities require a trip to other areas of campus. Internal mobility is impaired by both the CSX Railway and Cleveland Avenue, which bisect the campus and sometimes introduce unexpected travel time delays. Other regions are accessible by walking or shuttle bus, but Main Street affects this contiguity.

Central Campus is located directly south of Laird Campus, and is bounded by East Main Street to the north, Academy Street to the east, East Park Place to the south and South College Avenue to the west. It is oriented along the University's major north-south corridor, known as The Green, and is divisible into two areas: North Central and South Central. North Central functions as an academic hub, containing mainly classrooms with a small number of traditional residence halls. Following this trend, no dining hall is provided, but food is available at a nearby university center. Other amenities include a performance center and branch libraries. Internal mobility is impaired by East Delaware Avenue, which separates the academic buildings from the dormitories. North Central's counterpart, South Central, offers a wider variety of residence halls in addition to its academic buildings. Nearby amenities include a dining hall, the University's main library and the student health building. No obstructions prevent travel within South Central Campus.

West Campus is located directly west of Central Campus, and is bounded to the north by West Main Street and to the east by South College Avenue. It functions similar to North Central Campus, containing a variety of academic facilities but no dormitories. Amenities include several performance centers, two parking garages and the university center. Neighborhood streets have a small impact on internal mobility, but South College Avenue hinders travel to Central Campus.

East Campus is located directly east of Central Campus, and is only bounded to the west by Academy Street. Like Laird Campus, East Campus targets a uniform demographic, but instead focuses on freshmen. Design features such as double occupancy rooms, floor restrooms and community lounges help facilitate student interaction. East Campus is additionally the focus of a rehabilitation project known as the East Campus Housing Program, which consolidates freshmen into one location by shuddering dormitories on West Campus while constructing new accommodations locally. Amenities include an updated dining hall and student center, as well as recreational facilities. Haines Street is an example of a local street that divides East Campus with a marginal effect on mobility. Access to Central Campus, however, is inhibited by Academy Street.

Lastly, South Campus is the southernmost campus, which features more separation from the other regions. South Campus includes a few academic buildings for the College of Agriculture and Natural Resources and the College of Health Sciences while also featuring community-oriented facilities. These include several sports stadiums and a nurse managed health center. Mobility between the two colleges is affected by South College Avenue, while several city blocks and Amtrak's Northeast Corridor separate South Campus from Central Campus. Many surface parking lots are provided locally, so mobility issues are partially mitigated by a high frequency of bus service.

4.2 Scenario

The origin-destination matrix is being constructed to study the feasibility of operating a personal rapid transit system across the Newark campus. The case study is constructed to prove the ability of using existing data to approximate travel characteristics. Therefore, several assumptions have been made and limitations are present.

4.3 Student Schedules

The student schedule dataset was provided by the University, and contains information collected during the 2014 Fall Semester. All personal data was erased while retaining essential information, such as the student ID number and class characteristics. During this time, classes were provided in five regions (as defined by the University's asset labeling scheme): Central Campus, East Campus, North Campus, South Campus and West Campus. Figure 5 displays classroom locations across Newark, color-coding buildings to identify their location.

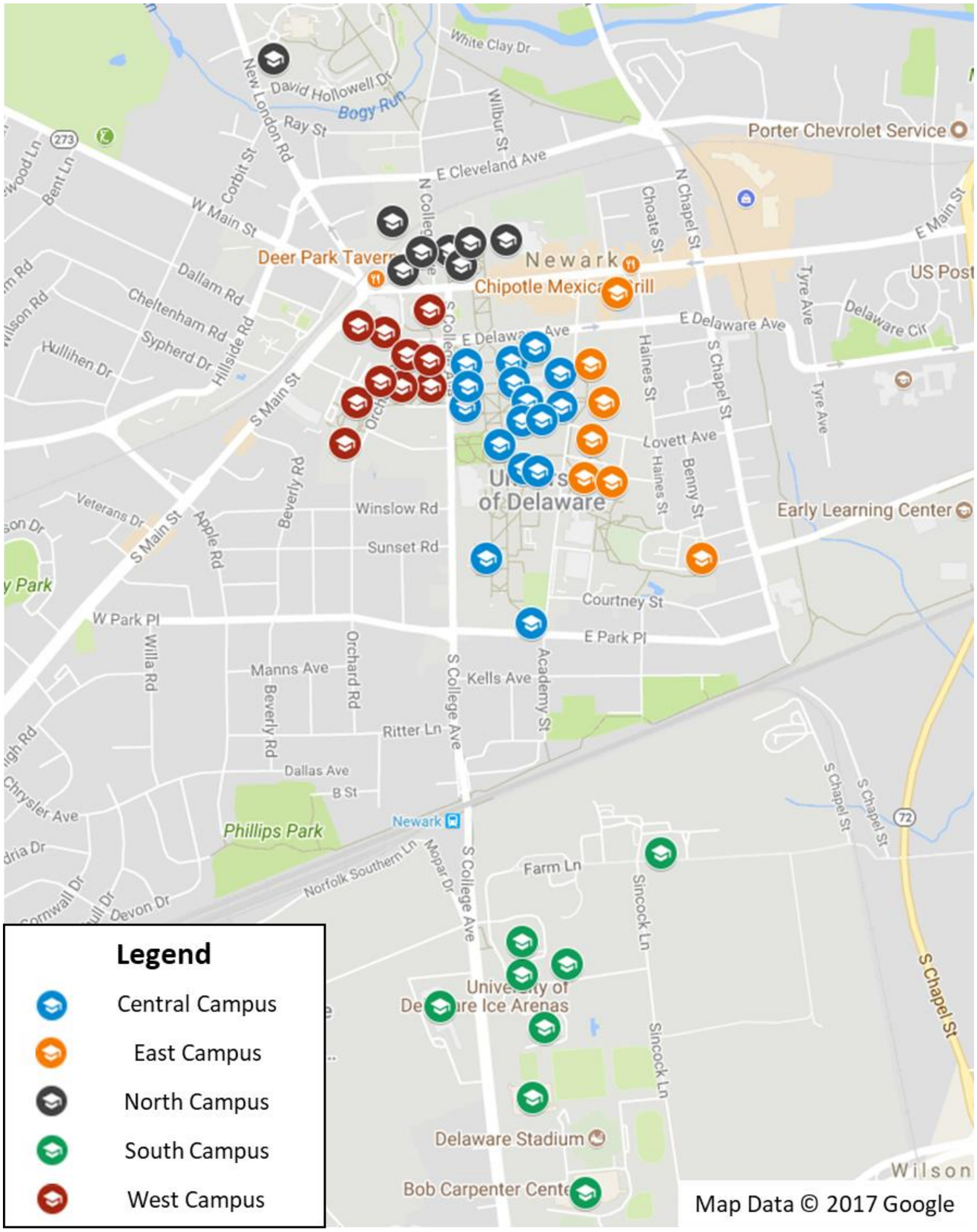

Figure 5: Classroom Locations (Google Inc., 2017)

4.4 Housing

Housing data, provided by the University, identifies the dormitory occupancy for the 2016 Fall Semester. Collected following the closure of residencies on West Campus, housing was provided in three regions: Laird Campus, Central Campus and East Campus. Figure 6 displays dormitory locations across Newark, applying a similar color scheme to identify buildings.

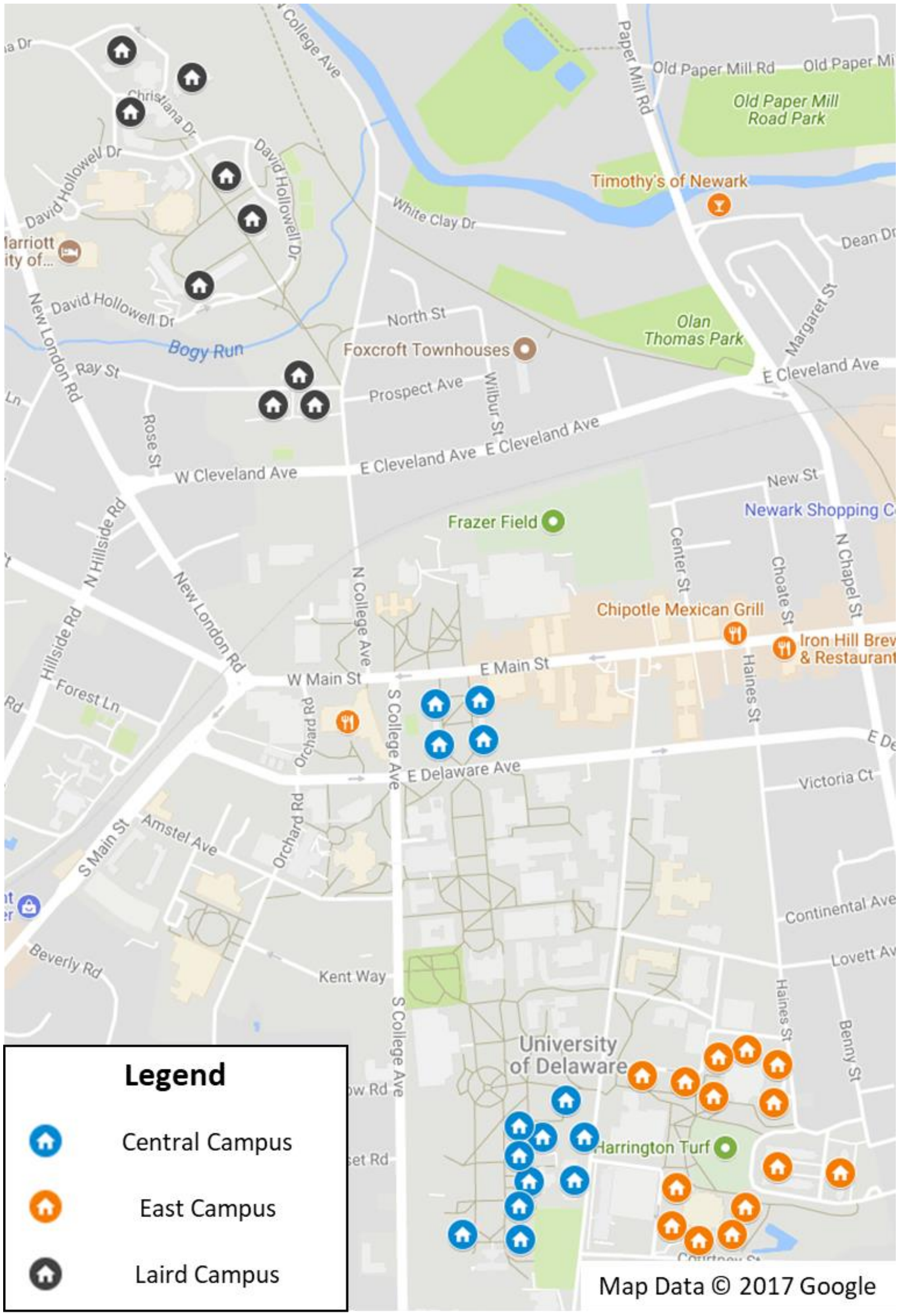

Figure 6: Housing Locations (Google Inc., 2017)

4.5 Parking

Parking data, provided by the University, contains an inventory of parking capacity throughout the campus for the 2016 Fall Semester. Spaces are classified into various permit categories, but permits relevant to students include: Red, Gray, and the Center for the Arts Parking Garage. Figure 7 displays parking locations across Newark with color-coding identifying required permit type.

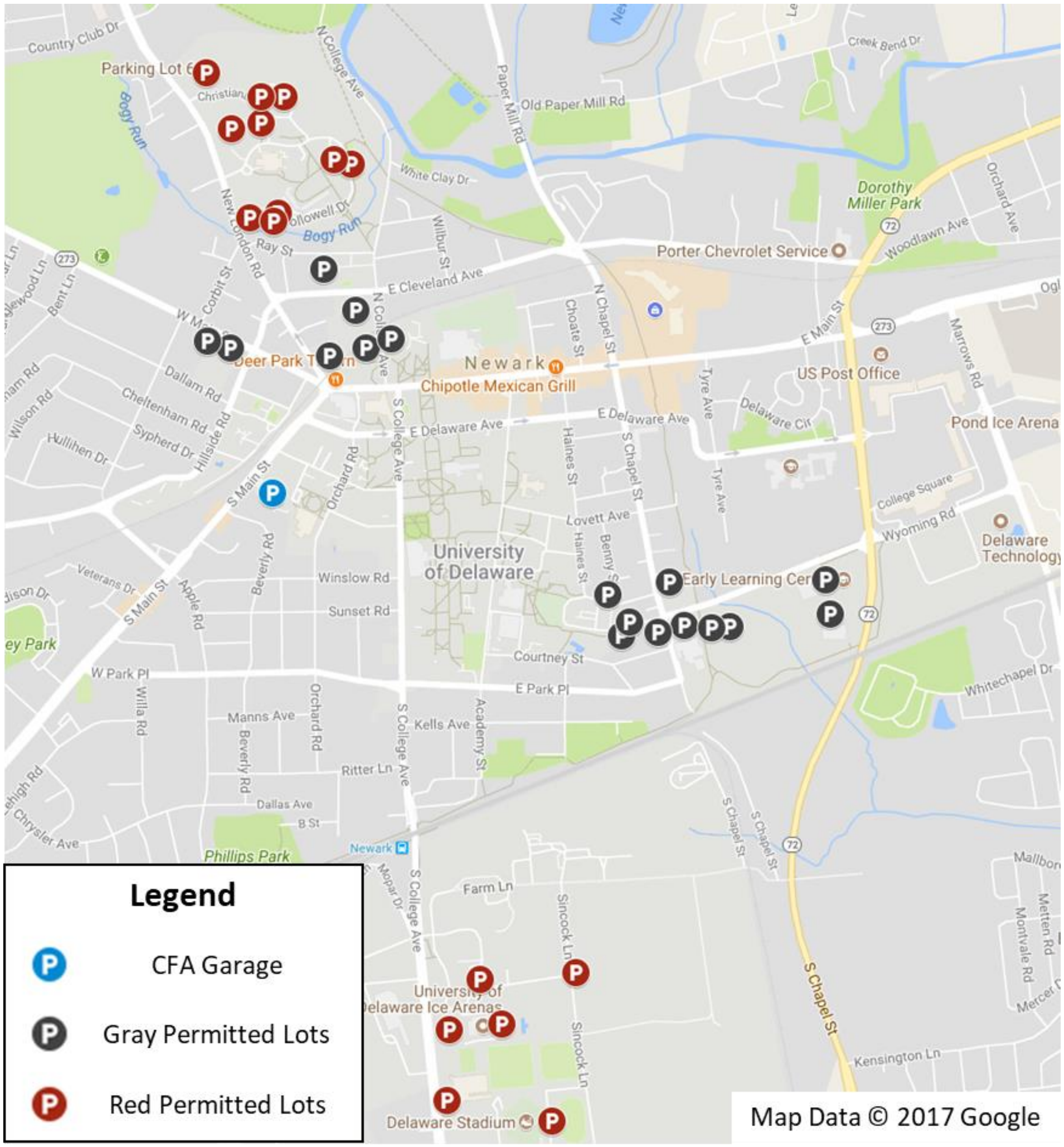

Figure 7: Parking Locations (Google Inc., 2017)

4.6 Analysis, Results, Discussion

Since the main objective for the research is to show the potential to construct an origin-destination matrix resembling student travel, the matrix will be verified by comparing it against known values. Therefore, analysis may be separated into three steps: verification of housing assumptions, verification of parking assumptions, and verification of travel demand.

4.6.1 Housing Verification

Verification of the housing assumptions involves comparing the known capacity of beds to the assigned demand for each dorm. Since the student data and housing data were compiled in different years, comparison is limited to the proportion of beds within each dormitory. This is summarized as the proportion of housing within each campus. When comparing the supply (Figure 8) to the assigned distribution (Figure 9), it is observed that the values are within a reasonable margin of error.

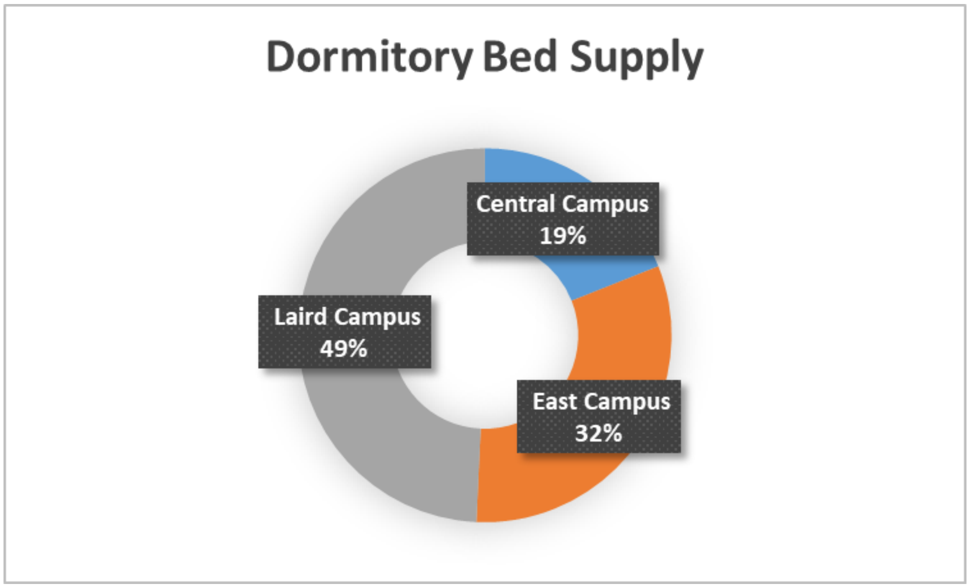

Figure 8: Proportion of Beds across Campus

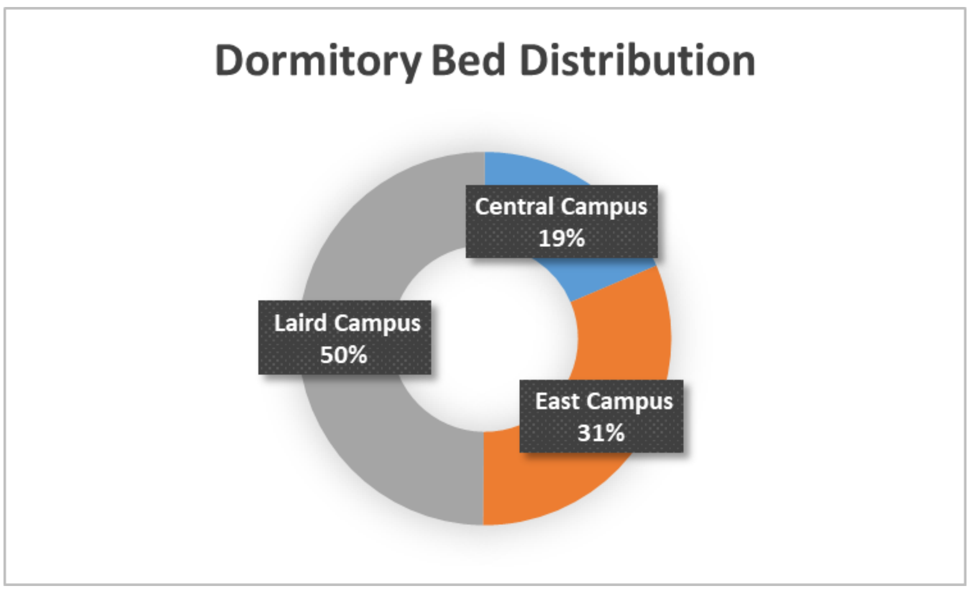

Figure 9: Actual Proportion of Beds assigned

4.6.2 Parking Verification

Like the housing verification process, the parking verification process may be completed by referencing the supply of parking stalls. Since the parking data was collected in a different year than the student data, the same limitation occurs whereby only the proportion of stalls may be considered, rather than the magnitude. This is summarized as the proportion of permits across Newark. When comparing the supply (Figure 10) to the assigned distribution (Figure 11), it is observed that the values are within a reasonable margin of error.

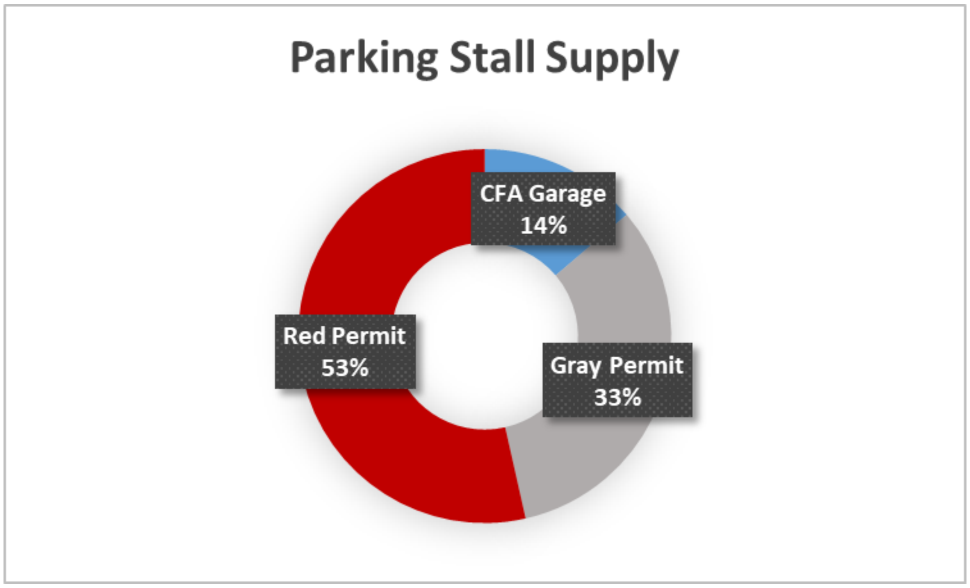

Figure 10: Proportion of Parking Stalls across campus

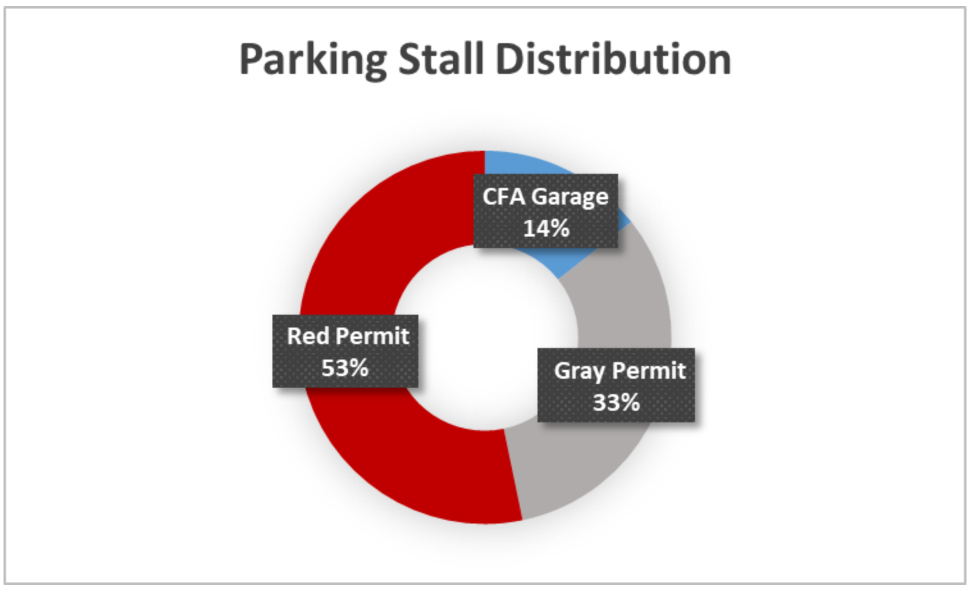

Figure 11: Actual Proportion of Parking Stalls assigned

4.6.3 Matrix Verification

The matrix verification process is more complex and involves multiple steps. The first step involves verifying the accuracy of the matrix internally. This consists of adding all the departures along with all the arrivals, and comparing the two. These values should be the same. The second step involves verifying the accuracy of the programming outputs: no trip, return trip from previous class, trip between classes, and trip to class. This was test by analyzing the number of classes that started directly after the exchange and ended directly before the exchange without a trip chain. It is observed that the trips projected by the matrix match the trips required by class attendance. Data from the origin-destination matrices are available upon request.

Figure 12 displays a portion of the origin-destination matrix for 7:30 a.m. to 8:00 a.m. travel period on Mondays. Locations are identified by their internal building code used by the University. The first step of matrix verification, internal consistency, may not be performed on this sample due to data exclusion. This sample, however, may be used to check the program's accuracy, fulfilling the requirements for Step 2. For example, the student schedule spreadsheet may be filtered to show all students arriving to class in Building NC03 at 8:00 a.m. on Monday morning. A search query may then be performed on the student home location spreadsheet to discover where students attending class are departing from. The search should reveal three students departing from Building NC04. On small sample sets, this process may be followed for each cell in the spreadsheet.

	NC02	NC03	NC04	NC05	NC06	NC07	NC10	NC12	NC13	NC14
NC02										
NC03										
NC04		3								1
NC05										
NC06										
NC07	2									
NC10										
NC12										
NC13										
NC14										

Figure 12: Sample of origin-destination matrix (Monday 7:30 a.m. – 8:00 a.m.)

Chapter 5

CONCLUSIONS, RECOMMENDATIONS, FUTURE RESEARCH

5.1 Conclusions

The proposed methodology provides a resource for transportation planners to build a model using preexisting data when challenged with a unique population. This is an advantage within the four-step modeling process, because it replaces the trip generation and trip distribution procedures. These procedures would otherwise require a resource-intensive study to be completed that created generalized travel assumptions.

5.2 Recommendations

Recommendations unique to this methodology involve enhancement of the program's operation to include easier user input. The program is currently written such that reference data needs to be formatted in a specific arrangement. Additionally, the user needs to be familiar with Visual Basic to change the variables relevant to unique scenarios (such as defining the weekday and time of day the travel matrix is representing). The program could be changed to include dialogs that would prompt the user for input, removing the need to be familiar with programming languages.

Recommendations general to the procedure include expansion of the research scope to include integration with a travel demand model. This thesis proves that it is possible to produce an origin-destination matrix that would input travel volumes into a model, but does not developed a specific process for so doing.

5.3 Future Research

To aid in the development process, several assumptions were made. Therefore, future research could involve elimination of these assumptions by supporting them with additional data. Assumptions include limitation of the population to students, limitation of trip purposes to class attendance, and availability of all dorms to all students.

5.3.1 Population Scope

Within this methodology, the modeled population is limited to undergraduate and graduate students. If students consist of a small proportion of the on-campus population, this could result in underrepresentation of travel demand. Therefore, the modeled population should be expanded to include both university faculty and staff. This could be accomplished following a similar procedure used with the student schedule document, by referencing a listing of offices and department locations. Since housing is provided exclusively for students, parking lots would serve as the default locations.

5.3.2 Trip Purpose Scope

Within this methodology, the exclusive trip purpose involves mandatory attendance of class sessions. In campus areas where many additional activities are available, such as dining, studying or relaxing, this could result in an underrepresentation of travel demand. Additionally, unnecessary return trips home might result in an overrepresentation of travel demand. Therefore, the modeled trip purposes should be expanded to include recreational activities. One way this could be implemented involves a procedure like that of the student housing and parking locations. Usage statistics from dining halls, student centers, libraries and fitness centers could be imported into a spreadsheet, and random numbers assigned to determine students using them. An additional step would involve ensuring that the student is free during that time, and verifying the last time when that student used the service. A second method involves distributing a student travel survey, for which generalized travel characteristics could be developed and assigned to the population.

5.3.3 Residency and Parking Requirements

Within this methodology, residence halls are equally available to all students. Increased accuracy of default student locations may be achieved by considering residency requirements for individual buildings. For example, the University of Delaware places restrictions on freshmen, requiring them to live in designated dormitories on campus, or at home with their parents. Additionally, a general requirement for all on-campus students requires them to purchase a meal plan to use at dining halls or convenience stores. These factors affect both the student's location as well as his or her travel habits.

A second way to increase the accuracy of a student's location involves consideration of parking restrictions. This methodology already limits parking opportunities to those available to students, but a time component is not considered. For example, after 5 p.m., the University of Delaware allows permitted vehicles into any lot not otherwise restricted. This means that the demand for a personal rapid transit system may substantially fall after this time.

5.3.4 Resource Limitations

Within this methodology, no resource limitations are considered. This means that the proportion of students housed at each location is equal to its relative availability with no consideration for magnitude. In instances where the supply and demand sources come from different years, this could cause an issue, since the number of students admitted may increase without the capacity for housing the additional students.

REFERENCES

Bustillos, B. I., Shelton, J., & Chiu, Y.-C. (2011). Urban university campus transportation and parking planning through a dynamic traffic simulation and assignment approach. *Transportation Planning and Technology, 34*(2), 177-197. doi:10.1080/03081060.2011.554670

Caceres, N., Wideberg, J. P., & Benitez, F. G. (2007). Deriving origin destination data from a mobile phone network. *IET Intelligent Transport Systems*, *1*(1), 15-26. doi:10.1049/iet-its:20060020

Collia, D. V., Sharp, J., & Giesbrecht, L. (2003). The 2001 national household travel survey: A look into the travel patterns of older Americans. *Journal of Safety Research, 34*(4), 461-470.

Eom, J. K., Stone, J. R., & Ghosh, S. K. (2009). Daily activity patterns of University Students. Journal of Urban Planning and Development, 135(4), 141-149. doi:10.1061/(ASCE)UP.1943-5444.0000015

Hawelka, B., Sitko, I., Beinat, E., Sobolevsky, S., Kazakopoulos, P., & Ratti, C. (2014). Geo-located Twitter as proxy for global mobility patterns. *Cartography and Geographic Information Science*, *41*(3), 260-271. doi:10.1080/15230406.2014.890072

Li, L., Yang, L., Zhu, H., & Dai, R. (2015). Explorative Analysis of Wuhan Intra-Urban Human Mobility Using Social Media Check-In Data. *PLoS ONE, 10*(8), e0135286. doi:10.1371/journal.pone.0135286

Martin, W. A., & McGuckin, N. A. (1998). *NCHRP Report 365: Travel Estimation Techniques for Urban Planning* (365). Retrieved from https://ntl.bts.gov/lib/21000/21500/21563/PB99126724.pdf

McNally, M. G. (2007). The Four-Step Model Handbook of Transport Modelling (pp. 35-53).

Stopher, P. R., & Greaves, S. P. (2007). Household travel surveys: Where are we going? *Transportation Research Part A: Policy and Practice, 41*, 367-381.

Wang, X., Khattak, A., & Son, S. (2012). What Can Be Learned from Analyzing University Student Travel Demand? *Transportation Research Record: Journal of the Transportation Research Board*, *2322*, 129-137. doi:10.3141/2322-14

Young, S., Miller, R., & Landman, E. (2004). Automated People Mover on a University Campus: Mobility Impact Analysis. Transportation Research Record: Journal of the Transportation Research Board, 1872, 56-61. doi:10.3141/1872-07

Appendix A

IDENTIFICATION OF VISUAL BASIC FUNCTIONS

A.1 CheckClassDay

This function occurs first and parses the student schedule spreadsheet to confirm that a class occurs during the appropriate weekday. If the class occurs during the same day represented by the OD matrix, the program progresses to the next function. Class occurrence is determined by Boolean vales in the student schedule document, and user input is required to select the matrix weekday via a numeric operator.

A.2 CheckBeginTime

This function occurs second, and parses the student schedule spreadsheet to confirm that a class starts during the appropriate time. Meeting start and end time are rounded to the nearest half-hour, so a class needs to begin directly after the travel interval. If a class begins during the correct time, the program progresses to the next function. Identifying the end of the travel time interval is done using a numeric operator specified by the user.

A.3 CheckEndTime

This function occurs after a failed instance of the CheckBeginTime function, and parses the student schedule spreadsheet to confirm that a class ends at the appropriate time. If a class ends during the correct time, the program progresses to the next function. Identifying the beginning of the travel time interval is done using a numeric operator specified by the user.

A.4 CheckTripChain

This function occurs after the CheckBeginTime function, and confirms that the class is participating in a trip chain. If classes are part of a trip chain, the origin will reflect the previous class. Otherwise, the origin will reflect the student default location. Regardless, the program will progress to the FindHomeLocation function.

A.5 FindHomeLocation

This function parses the student housing location spreadsheet to determine the default student location of the individual attending the class. The default student location could correspond to either a dormitory or parking lot. When a matching StudentID is found between the spreadsheets, the program progresses to the next function.

A.6 PriorClassLocationOrigin

This function occurs when the previous class serves as the origin for a trip. It parses the rows in the OD matrix to find a location matching the previous class in the student schedule spreadsheet. Upon finding a matching class, the program continues to the ClassLocationDestination function.

A.7 HomeLocationOrigin

This function occurs when the student default location serves as the origin for a trip. It parses the rows in the OD matrix to find a location matching the student default location in the student housing spreadsheet. Upon finding a matching location, the program continues to the ClassLocationDestination function.

A.8 ClassLocationDestination

This function occurs when the class serves as the destination for a trip (either the previous class or student default location must serve as the origin). It parses the columns in the OD matrix to find a location matching the class in the student schedule spreadsheet. Upon finding a matching location, the cross-section of the two locations is known, and the value of this cell is increased by 1. The program then returns to the CheckClassDay function.

A.9 ClassLocationOrigin

This function occurs when the class serves as the origin for a trip (return trip home when class is not part of a trip chain). It parses the rows in the OD matrix to find a location matching the class in the student schedule spreadsheet. Upon finding a matching location, the program continues to the HomeLocationDestination function.

A.10 HomeLocationDestination

This function occurs when the student default location serves as the destination for a trip. It parses the columns in the OD matrix to find a location matching the location in the student housing spreadsheet. Upon finding a matching location, the cross-section of the two locations is known, and the value of the cell is increased by 1. The program then returns to the CheckClassDay function.

Appendix B

OPERATORS FOR VISUAL BASIC FUNCTIONS

Table 3: Operators for CheckClassDay

Operator	Description
9	Monday
10	Tuesday
11	Wednesday
12	Thursday
13	Friday

Table 4: Operators for CheckBeginTime

Operator	Description
1	7:30:00 AM
2	8:00:00 AM
3	8:30:00 AM
4	9:00:00 AM
5	9:30:00 AM
6	10:00:00 AM
7	10:30:00 AM
8	11:00:00 AM
9	11:30:00 AM
10	12:00:00 PM
11	12:30:00 PM
12	1:00:00 PM
13	1:30:00 PM
14	2:00:00 PM
15	2:30:00 PM
16	3:00:00 PM
17	3:30:00 PM
18	4:00:00 PM
19	4:30:00 PM
20	5:00:00 PM
21	5:30:00 PM
22	6:00:00 PM
23	6:30:00 PM
24	7:00:00 PM
25	7:30:00 PM
26	8:00:00 PM
27	8:30:00 PM
28	9:00:00 PM
29	9:30:00 PM
30	10:00:00 PM