Effect of Service, Temporal, and Weather Variables on Short Bus Transit Passenger Trips: Investigations of OSU’s Intra-campus Transit Demand

Thesis

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ABSTRACT

Transit agencies and transportation planners use knowledge of passenger demand and travel flow patterns in an urban area to make decisions about the service they provide. Understanding demand supports decisions about service frequency, bus stop locations, and route alignment to provide efficient and effective service. The demand for transit usage depends on the service provided, the trip purpose of the traveler, and the different land uses served. This study focuses on the demand for short passenger trips.

Specifically, the demand of intra-campus passenger flow on the Campus Area Bus Service (CABS) at The Ohio State University (OSU) is investigated. Intra-campus travel demand was selected as the focus of this study for several reasons. First, this demand can be estimated by the Automated Passenger Counter (APC) data that OSU’s Campus Transit Lab (CTL) provides. Second, providing a free service to all its passengers, CABS buses can be considered an equal alternative to walking in terms of out-of-pocket cost. Third, because walking is considered an equal alternative to taking a CABS bus for intra-campus travel, the choice between the bus and walking depends on common factors.

The metropolitan city-like structure of the Ohio State University campus makes it a small scale representation of larger urban areas and transit services. Therefore, certain aspects of the findings are expected to have implications in larger systems.
Bus passenger origin-destination (OD) flow matrices are estimated for each bus trip from boarding and alighting data automatically collected on the buses. These trip level OD matrices are aggregated by the date and time-of-day period in which they occurred for each route. Intra-campus variables are calculated from the aggregated OD matrices, and temporal and service frequency variables are determined to provide information corresponding to the intra-campus values. In addition, hourly temperature and precipitation values are included as explanatory variables.

The accumulation of these data allow for an estimation of regression models. The models indicate that very low or very high temperatures increase intra-campus passenger volume and proportion. It was found that the 60°F to 80°F temperature range produces the lowest intra-campus travel demand on CABS. Precipitation also increases CABS intra-campus ridership, likely because the bus provides a shelter from the negative effects of precipitation that would be encountered if choosing the competing walking alternative. In addition, the nature of the inter-route headways considering routes that share a similar intra-campus alignment has a statistically significant effect on intra-campus demand on both routes, indicating that route competition does affect the route choices passengers make.

This study demonstrates that models can capture relationships of interest between multiple explanatory variables and intra-campus demand. The multiple models estimated allow for an examination of intra-campus demand at the level of an individual route and at the campus-wide level, both in terms of intra-campus volume and intra-campus proportion. Considering results from both volume and proportion models allows for a
greater understanding of factors affecting intra-campus demand than if only a volume or proportion model had been considered.
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CHAPTER 1

INTRODUCTION

1.1 Background

Transit agencies and transportation planners use knowledge of passenger demand and travel flow patterns in an urban area to make decisions about the service they provide. Understanding demand supports decisions about service frequency, bus stop locations, and route alignment to provide efficient and effective service. The demand for transit usage depends on the service provided, the trip purpose of the traveler, and the different land uses served. For example, systems may serve discretionary or obligatory trips, short or long trips, and trips made for work, school, shopping, or social purposes. Different temporal patterns in demand will be seen on segments serving the Central Business District than on segments serving shopping centers. The goal of this thesis is to analyze and explain the demand for short trips where walking is a viable alternative as a function of variables of interest that can be interpreted.

Specifically, this study examines the demand of intra-campus passenger flow on the Campus Area Bus Service (CABS) at The Ohio State University. The CABS provides
service for a variety of trip purposes and passenger types. It seeks to be accessible to people who live on or near campus, to provide transport for commuters who park in off-campus lots, and to serve many destinations around campus to provide efficient and convenient service for its users. Due to limited parking and congestion around main campus, much of the CABS passenger demand occurs for those who seek service between off-campus parking lots or nearby residential areas and the main campus. Trips between these off-campus locations and main campus bus stops are generally long enough that walking is not considered a viable option. For example, the West Campus Parking Lot, the largest parking lot for commuters, is located over two miles away from the main campus with several impediments to walking occurring along the way.

In this study, an intra-campus passenger trip is defined as a trip that occurs between a boarding bus stop and an alighting bus stop that are both considered to be located on main campus. Main campus is where the majority of dormitories, recreation centers, libraries, and classrooms are located. Intra-campus passenger trips are considered trips where there is a choice among modes. Providing a free service to all its passengers, riding a CABS bus can be considered an equal alternative to walking in terms of out-of-pocket cost. The size of the campus also makes walking a viable option for travelers to utilize. Most destinations in the main campus area are less than one mile apart, and therefore, can be walked by college students within a short period of time. For example, the longest trip that could occur on main campus would be from the northeast corner of main campus, the intersection of Lane Ave. and High St., to the Medical Center in the southwest corner of main campus. The distance between these two locations is about 1.2
miles and can be traversed by walking in less than 20 minutes, assuming normal walking conditions.

The Campus Transit Lab (CTL 2013) at The Ohio State University provides the resources needed to perform an analysis of this scope. CTL has a large set of Automated Passenger Counter (APC) data collected since 2009 for use in demand estimation. Working closely with the CABS, CTL has provided an understanding of the transit system operation and travel movements on The Ohio State University campus. Data availability and familiarity of the passenger flow patterns on campus enable intuitive interpretation and validation of results regarding the factors believed to affect the intra-campus travel demand for passengers taking CABS buses. CTL and APC are further discussed in Section 2.2.

Intra-campus bus passenger travel demand was selected as the focus of this study for several reasons. First, the characteristics of this demand can be estimated using existing technologies on CABS buses. Specifically, all CABS buses are equipped with APC devices that measure boarding and alighting counts at bus stops. The boarding and alighting counts are used to estimate origin-destination (OD) matrices. Second, because walking is a competitive alternative to taking a CABS bus for intra-campus travel, flows can indirectly lead to an understanding of walking trips. Due to the long distances of non-intra-campus travel and limited parking availability, passenger demand for non-intra-campus trips can be considered to serve a more “captive” travel sector. As such, non-intra-campus demand is not expected to change greatly based on factors like weather or service frequency. It is also known that intra-campus travel demand on CABS is high
and is therefore an important component of the total demand of CABS usage. With continual changes in campus development, increasing enrollment and new technologies available to assist passengers in planning their CABS trip, the intra-campus travel using CABS is expected to continue being a significant proportion of the total CABS usage.

The metropolitan city-like structure of the Ohio State University campus makes it a small scale representation of larger urban areas and transit services. Therefore, certain aspects of the findings are expected to have implications for larger systems.

1.2 Thesis Organization

The rest of this thesis is organized as follows. Chapter 2 explains the process of developing the intra-campus variables. The collection of the passenger volume data using APCs and the transformation of the data into intra-campus volumes is be described, as well as the transformation of the data into the intra-campus dependent variables used in the modeling. The explanatory variables used in the modeling are also introduced and the determination of the appropriate values is explained. Chapter 3 provides the motivation and logic for the various models developed and the justification and expectations of the explanatory variables included in the models. In addition, model results are presented and analyzed. Chapter 4 summarizes the results of the study and provides ideas for future research.
CHAPTER 2

DATA AND VARIABLES

2.1 Overview

This chapter explains the process of collecting passenger volume data, the transformation of the data into variables that represent intra-campus travel, and the determination of explanatory variables that correspond to the intra-campus travel.

Bus passenger origin-destination (OD) flow matrices are estimated for each bus trip from boarding and alighting data automatically collected on the buses. These trip level OD matrices are aggregated by the date and time period in which they occurred for each route. Intra-campus variables are calculated from the aggregated OD matrices and temporal and service frequency variables are determined to provide information corresponding to the intra-campus values. In addition, hourly temperature and precipitation values were obtained to be included as possible explanatory variables. The accumulation of these data, observations, and explanatory variables allow for a comprehensive analysis through the estimation of regression models, presented in Chapter 3.
2.2 Campus Transit Lab

CTL at The Ohio State University is a result of a collaborative effort between CABS, transportation-related technology companies, and research students and faculty aimed at supporting transit research, education, and outreach. CTL uses many state-of-the-art automated technologies that collect data to enable the research team to facilitate understanding, test and generate research hypotheses, compare the performance of alternative methodologies, and refine promising developments. An overview of the routes CABS provides and descriptions of the main campus areas they serve are explained in section 2.2.1.

One of the technologies the CABS buses are equipped with are APCs. These devices are used to collect data central to this study. Their functionality is described section 2.2.2.

2.2.1 Routes

Intra-campus passenger flows on four bus routes were estimated using APC data. These routes are: Campus Loop South (CLS), Campus Loop North (CLN), North Express (NE), and Central Connector (CC). Some routes have been somewhat modified over the past several years due to new services, campus development, and construction. There were no major route adjustments and all of the route changes were accounted for in the intra-campus flow calculations. A current route map for the 2012 – 2013 academic year is
shown in Figure 1. Additional route maps from the previous academic years are included in Appendix A.

Figure 1: 2012 – 2013 Academic Year CABS Route Map
For this study, the main campus area is included in the polygon shown in Figure 1 and is defined as the region enclosed by Lane Avenue, High Street, the Olentangy River (excluding St. John), and 12th Avenue, as well as the Medical Center in the southwest corner of campus.

The CLS route services the West Campus Parking lot, along with Ag Campus, and then traverses a counter-clock-wise loop around the main campus boundaries serving the medical campus, dormitories, student services facilities, and academic buildings before going back to the West Campus parking lot. The route has remained the same since Autumn Quarter 2009. The stops in the main campus for CLS are: Drake Union, Cannon Dr. & 12th Ave., Med Center & Cannon Dr., Med Center & 9th Ave., Neil Ave. & 10th Ave., Mack Hall, Hale Hall, Ohio Union Northbound, Arps Hall, North Dorms, and Fisher College of Business.

The CLN route services similar stops as CLS, starting at the West Campus Parking lot, followed by the Ag Campus, and then traversing a clock-wise loop around the main campus boundaries serving the same areas served by CLS in the opposite direction before going back to the West Campus parking lot. This route has also remained the same since Autumn Quarter 2009. The stops in the main campus for CLN are: Knowlton Hall, Koffolt Lab, Stillman Hall, Ohio Union Southbound, Honors House, Hamilton Hall, 9th Ave. & Meiling Hall, Med Center & Cannon Dr., Cannon Dr. & 12th Ave., and Mid Towers.
The NE route, similar to the CLS and CLN routes, primarily serves the West Campus parking lot and the academic core portion of the main campus area. It traverses a smaller loop around the center of the main campus, rather than the loop around the boundaries of the main campus. This route has the shortest cycle time (bus trip duration) of all the routes CABS provides and has remained the same since Autumn Quarter 2009. The six stops in the main campus for NE are: RPAC Loop, University Hall, 17th & College Ave., Arps Hall, North Dorms, and Fisher College of Business.

The CC route began its service at the beginning of Autumn Quarter 2010. Its initial purpose was to exclusively serve intra-campus passengers. In the 2010 – 2011 academic year, the entire route was considered in this study as part of the main campus, and therefore, every passenger trip was considered as an intra-campus trip. These stops are: Drake Union, Mid Towers, Knowlton Hall, Watts Hall, Stillman Hall, Ohio Union Southbound, Honors House, Hamilton Hall, 9th Ave. & Meiling Hall, 10th Ave. & Meiling Hall, Mack Hall, Hale Hall, Ohio Union Northbound, Arps Hall, North Dorms, and Fisher College of Business.

In its second year of operation, the 2011-2012 academic year, the CC route expanded to include some off-campus residential areas south of campus, and therefore, was no longer considered an exclusively intra-campus route in this study. The same main campus stops continued being served as in the first year, with the exception of the 10th Ave. & Meiling Hall stop, and two more main campus stops were introduced, the Med Center & Cannon Dr. and the Neil Ave. & 10th Ave. bus stops. In addition, three new stops introduced
were not considered main campus stops, King Ave. & Cannon Dr., King Ave. & Michigan Ave., and Neil Ave. & 8th Ave.

In the 2012 Autumn Semester, the CC route expanded again, serving six off-campus residential bus stops, as well as one stop at the Battelle Memorial Institute. The 9th Ave. & Meiling Hall main campus stop was no longer part of the route and additional off-campus stops that were added include: Neil Ave. & 7th Ave., Neil Ave. & 5th Ave., Michigan Ave. & 5th Ave., and Battelle Blvd. & 6th Ave.

The East Residential (ER) bus route is designed to serve the largest off-campus residential area, located to the east of the main campus. It serves over 20 off-campus residential bus stops on 4th Street and Summit Avenue, as well as a few commercial stops on High Street. The route has the following main campus bus stops: Ohio Union Northbound, Arps Hall, Physics Research, Neil Ave. & 17th Ave., University Hall, 17th & College Ave., and Ohio Union Southbound. ER has gone through many realignment and stop changes since Autumn Quarter 2009, but most of these changes have occurred in the off-campus residential area. The main campus stops had one adjustment during the Autumn Quarter 2009 to Autumn Semester 2012 time period, due to campus construction that occurred in Spring Quarter 2012. In that quarter the main campus stops were: Ohio Union Northbound, Arps Hall, Physics Research, Baker Systems, Stillman Hall, and Ohio Union Southbound.

The ER route was not included in this intra-campus flow study due to the incompleteness of the data for the time frame considered in this research. The ER route preexists the
2009-2010 academic year, but the APC data was not available until Autumn Quarter 2010. This co-aligns with the introduction of the new CC route. Since one area of interest in this study is the effect of the new CC route on intra-campus travel, the available ER data was not included to prevent an overestimation of this effect. The omission of the ER data should not have a significant impact on the conclusions of this study because it is primarily used by students living off campus travelling to and from campus and thus contribute very little to intra-campus flows. This is particularly so because the route serves few main campus stops that are located relatively close to each other, such that walking these distances would not take much longer than taking an ER bus.

There are two other CABS bus routes that offer intra-campus service that were not included in this study. The Buckeye Village (BV) route, which goes back and forth between a large off-campus residential community north of campus and the main campus, did not have APC data available. It serves the same intra-campus stops as NE. Also, the Med Center Express (MC) route is a service that loops around the medical area of campus in the southwest corner of main campus and goes to the Buckeye parking lot several miles north of campus. These two routes provide minimal intra-campus travel due to the limited number of main campus stops, as well as the close proximity of the main campus stops they serve, where walking is often by far a superior mode. Therefore, it is believed that excluding these two routes from this study does not have any significant impact when analyzing intra-campus passenger flows.
2.2.2 Automated Passenger Counter Data

On every CABS bus sensors are located at the front and back entrance doors to measure the number of passengers that board and alight at each bus stop. These APCs, installed by Clever Devices, collect boarding and alighting counts at every stop. The APCs run continuously while the buses are in service. APC installation began on CABS buses in 2008 and was completed and tested on all buses before Autumn Quarter 2010 service commenced. The data are exported to the Campus Transit Lab server for research purposes.

These data are typically used for examining passenger boarding and alighting volumes at bus stops, as well as total trip volumes, and can be helpful to planners for bus service scheduling and forecasting. They can also be used to estimate OD passenger flows on buses as discussed subsequently.

2.3 Dependent Variables

This thesis analyzes intra-campus passenger flows and variables that affect them using regression analysis. The intra-campus passengers per hour and intra-campus percentage among total travel are the two dependent variables considered in this study. The intra-campus passengers per hour variable represents the volume of passengers that use CABS for intra-campus travel. This variable reflects the quantity of intra-campus travel demand. The intra-campus percentage among total travel variable represents the
proportion of intra-campus passenger travel to total passenger travel between all the OD pairs of a route. This variable reflects the probability that a passenger travels between intra-campus OD pairs. The intra-campus passenger volumes per hour and percentage variables are determined for the individual routes, CLN, CLS, and NE, as well as for the routes combined, which include the CC, CLN, CLS, and NE routes. This allows the intra-campus travel to be analyzed system-wide, as well as on an individual route basis.

In addition, the intra-campus passengers per hour variable for the CC route is analyzed, but the intra-campus percentage variable for the CC route is not. The intra-campus passenger volumes on CC are of interest because the route has served almost all the same main campus stops throughout the study and thus the demand for travel between these stops is analyzed. However, because of the major route changes that have occurred during the period of interest, the intra-campus percentage value is not meaningful to analyze because of the addition of off-campus stops over time. That is, the first year of the CC service had daily values of 100% for intra-campus percentage, but was reduced in the remaining terms due to the addition of these off-campus stops. In what follows, the determination of the two dependent variables of interest is described in detail.

2.3.1 Bus Trip Level Origin-Destination Matrices

Passenger boarding and alighting counts at every bus stop do not provide direct information on OD flows for individual passengers. In this study, the Iterative Proportional Fitting procedure with a null base (Ben-Akiva et al. 1985, Mishalani et al. 1985).
referred to as IPF-null, is used to estimate OD flows from boarding and alighting counts. The null base reflects the assumption that no prior OD passenger flow pattern is known, whereby initially all possible OD pairs are assumed equally likely to be traveled between by a random passenger. The IPF-null procedure updates the null base matrix in an iterative fashion until the boarding and alighting counts calculated from the OD flow estimates are equal to the corresponding observed counts. The IPF-null method has been found to perform relatively well at estimating general patterns in OD flows, based on empirical studies where estimates are compared to ground truth observations (McCord et al. 2010, Strohl 2010, Ji et al. 2011).

The IPF-null procedure was applied using a Matlab code to determine the OD passenger flows from the APC data for every CABS trip during the academic terms considered. These estimated trip level OD matrices were saved in Matlab files corresponding to the bus route and academic term in which they occurred.

2.3.2 Route Level Origin-Destination Period Matrices

A Matlab program filters and aggregates trip level OD matrices into four daily time intervals in order to produce time-of-day estimates of intra-campus passenger flows. A flow chart of this process is presented in Figure 2.
Consider specific route and academic term OD records and route parameters

Filter applied to eliminate outlier bus trip data and non-school days

Select first school day of term

OD matrices are aggregated into four time-of-day periods

Stop grouping is applied to the four time-of-day OD matrices

Determine intra-campus volumes and percentages by time-of-day

Select next school day of term

Is the term over?

Have all terms been run?

Have all routes been run?

End

Figure 2: Flow Chart for Filtering and Aggregation Process
As illustrated in the figure, a specific bus route and academic term’s bus trip level OD matrices are input to the analysis. In addition, parameters indicating which OD pairs are considered intra-campus OD pairs for a route are used as input. Bus trips that are considered “bad” trips because of likely APC error resulting in outliers are first filtered out. Specifically, a bus trip is considered a “bad” trip if the differences in total boarding and total alighting counts (for a bus trip) are greater than five or the total passenger count on a bus trip is greater than 150. In addition, trips that occur on holidays and weekends are filtered out.

Next, a loop is initiated to aggregate the trip level OD flows that pass the filter requirements into four time-of-day periods. The time-of-day periods are created to smooth out the differences in passenger volumes on individual bus trips. The loop starts from the first school day of the term and sums the corresponding OD cells of all of the individual bus trips. The time-of-day periods are: 8 AM – 10 AM, 10 AM – 1 PM, 1 PM – 3 PM, and 3 PM – 5 PM. These time-of-day periods are determined based on the research team’s understanding of campus travel. A bus trip belongs to a period if the departure time from the terminal falls within that period.

To better understand passenger OD flow patterns, certain stops on some routes are combined. For a CLS OD matrix, the four bus stops surrounding the West Campus parking lot are combined because they all serve passengers who park in the West Campus parking lot and ride the buses to various destinations on campus. The same four West Campus parking lot bus stops are combined for the CLN and NE routes also. For the CC route, the Drake Union and Mid Towers bus stops are combined because the two stops
are consecutive and across the street from each other. At this stage of the data processing the necessary stops are grouped to form updated OD flow matrices that reflect this grouping. The stops that are grouped are different for each route and are indicated as inputs to this step.

Next, intra-campus related variables are calculated using the route variables determined from previous steps. The following values corresponding to the time-of-day are recorded: date, number of “good” trips, number of total trips, and number of passengers on the “good” trips. The following are then calculated: scaled-up number of estimated total passengers, scaled-up estimate of intra-campus passenger flows, and intra-campus flow percentages. The process and calculations used to determine these values are explained in Section 2.3.3. As shown in Figure 2, this process is repeated for every day of the academic term, then for every academic term dating back to Autumn Quarter 2009. The process is also repeated for all the bus routes for which data is available.

2.3.3 Route Level Intra-Campus Passenger Volumes and Percentage

Figure 3 is an example of an aggregated OD passenger flow matrix for CLS between 8 AM to 10 AM on October 25, 2011. The matrix is formed by aggregating 13 bus trips on the CLS bus route departing the terminal stop between 8 AM and 10 AM. One additional trip occurred between 8 AM and 10 AM on October 25, 2011, but was filtered as a “bad” trip. The total number of passengers (557) on the 13 trips used is calculated by summing the values across all the OD cells of the matrix. The shaded (yellow) cells represent the
intra-campus OD pairs. The summation of the flows in these cells (183.13), divided by the total (557), result in the intra-campus percentage. In this example, the intra-campus percentage is 32.9%.

![CLS Origin-Destination Matrix from October 25, 2010 between 8-10 AM](image)

To account for different proportions of filtered trips in different records when considering the intra-campus flow volumes, the numbers of estimated passengers are scaled up according to the proportion of the number of total trips to the number of trips that remain after filtering out the “bad” trips. In the case indicated in Figure 3, there would be: 557
passengers x 14 total trips / 13 “good” trips = 599.84 total passengers and 183.13 intra-campus passengers x 14 total trips / 13 “good” trips = 197.22 intra-campus passengers.

Table 1 presents the resulting values for this example and examples for three additional dates.

<table>
<thead>
<tr>
<th>Date</th>
<th>CLS &quot;Good&quot; Trips</th>
<th>CLS Total Trips</th>
<th>CLS &quot;Good&quot; Trip Passengers</th>
<th>CLS Total Passengers</th>
<th>CLS Intra-Campus Percentage</th>
<th>CLS Intra-Campus Passengers</th>
</tr>
</thead>
<tbody>
<tr>
<td>10/25/2011</td>
<td>13</td>
<td>14</td>
<td>557.00</td>
<td>599.85</td>
<td>32.88%</td>
<td>197.22</td>
</tr>
<tr>
<td>10/26/2011</td>
<td>7</td>
<td>14</td>
<td>277.00</td>
<td>554.00</td>
<td>30.30%</td>
<td>167.87</td>
</tr>
<tr>
<td>10/27/2011</td>
<td>12</td>
<td>14</td>
<td>592.00</td>
<td>690.67</td>
<td>34.99%</td>
<td>241.69</td>
</tr>
<tr>
<td>10/28/2011</td>
<td>12</td>
<td>14</td>
<td>412.00</td>
<td>480.67</td>
<td>34.17%</td>
<td>164.26</td>
</tr>
</tbody>
</table>

Values for the intra-campus passengers per hour variable are calculated for the individual routes by dividing the estimated number of intra-campus passengers by the duration of the time interval. These variables are determined for the purpose of comparing intra-campus passenger volumes across time-of-day intervals, since the 10 AM to 1 PM period is three hours long, while the other periods are two hours long. For the example, since the 8 AM to 10 AM period is two hours in duration, the CLS intra-campus passenger’s value, 197.22, is divided by two. This results in a value of 98.61 intra-campus passengers per hour.

The final route level dependent variables used for the modeling in Chapter 3 are: CLN intra-campus passengers per hour, CLN intra-campus percentage, CLS intra-campus
passengers per hour, CLS intra-campus percentage, NE intra-campus passengers per hour, NE intra-campus percentage, and CC intra-campus passengers per hour.

### 2.3.4 Combined Route Intra-Campus Passenger Volumes and Percentage

To determine the intra-campus volumes across the routes, all of the routes’ data are matched by their corresponding date and time-of-day period. Records that did not have any “good” trips for at least one of the routes that was in service are eliminated to avoid biased values (zero bus trips cannot be scaled up).

The combined route total number of passengers and intra-campus passengers are calculated by summing the respective scaled-up values across all the routes. The combined route intra-campus passengers per hour values are calculated by dividing the number of intra-campus passengers by the duration of the time interval. The combined route intra-campus percentage is calculated by dividing the total intra-campus passengers by the total number of passengers.

### 2.4 Service Frequency Variables

Service frequencies are considered as possible explanatory variables in the analysis. The total number of bus trips is determined in the period level OD aggregation process. This total number includes the “bad” or outlier trips that are initially filtered out. Trips per
hour values for the individual routes are calculated by dividing the total number of trips including the outliers by the duration of the time interval.

The total bus trips across all the routes are summed. A combined route trips per hour variable is similarly calculated by dividing the total trips by the duration of the time interval. This variable is of interest especially when developing a combined model for all the routes.

2.5 Headway Ratio Variables

In addition to frequency, the nature of inter-route headways could have an effect on route demand in the cases where more than one route serve certain OD pairs. To capture this possible route interaction, a variable is defined and calculated as described next.

The CLS & CLN routes each share seven consecutive on-campus bus stops with CC. This represents 28 possible intra-campus OD pairs where a passenger could choose between taking a CLS or CC bus if they are traveling northbound. Similarly, there are 28 southbound intra-campus OD pairs a passenger could travel choosing either a CLN or CC bus. Ratios of the headway between the CC and CLS (or CLN) buses to the CLS (or CLN) headway at the first bus stop they share were calculated and averaged over the time-of-day periods for every day. The resulting variables indicate the likelihood that a randomly arriving passenger will encounter a CC or a CLS (or CLN) bus. The details of the calculations are described next.
For the CLS-CC Headway Ratio variable, the value is calculated by dividing the difference in time between the arrival of a CLS bus at the Neil & 10th bus stop from the next CC bus that arrives at the Neil & 10th bus stop by the difference between the same CLS bus arrival time and the next CLS bus arrival time at the Neil & 10th bus stop. This ratio is calculated for every CLS bus that arrives within the 8 AM to 5 PM for every day and the average is taken for each of the time-of-day periods for every day. This calculation is done similarly for the CLN-CC Headway Ratio at the Knowlton Hall bus stop. Since the competing routes follow the same path between the seven bus stops in either direction with limited service control intervention, the distribution of the headways between the buses at each of these stops is assumed to remain the same.

A value of 0.5 for the CLS-CC Headway Ratio indicates that for a specific day’s time-of-day period, on average, a CC bus arrived at the Neil & 10th bus stop exactly between two CLS buses. This would indicate that a randomly arriving intra-campus passenger would be equally likely to take a CC or CLS bus assuming that they board the first bus that arrives. A value greater than 0.5 implies that a randomly arriving passenger would be more likely to take a CC bus, and, conversely, a value less than 0.5 indicates that a randomly arriving passenger would be more likely to take a CLS bus. Similar interpretations apply to the CLN-CC interaction case. And, as the headway ratio variable becomes closer to 0 the probability of a passenger traveling between one of the 28 intra-campus OD pairs is more likely to choose the CLS or CLN route, rather than the CC route. Similarly, as the headway ratio becomes closer to 1.0, the probability of a passenger traveling on one of these ODs is more likely to choose the CC route.
A value of 0 for the CLS-CC Headway Ratio indicates that the CC route was not in service for that day and time-of-day period. Therefore, passengers traveling between one of the possible intra-campus OD pairs would not have a choice but to take a CLS bus. The same applies to the CLN-CC interaction case. Since the CC route was nonexistent in the first academic year of this study, the CLS-CC and CLN-CC Headway Ratio values are 0 for the entire 2009-2010 Academic year.

2.6 Temporal Variables

Similarly, temporal variables are of interest as possible explanatory variables. Regarding time-of-day, indicator variables are used. A particular time-of-day variable takes the value of ‘1’ if the record belongs to that time-of-day. In addition, the day-of-week, term, and academic year variables are similarly determined. For example, if an observation occurred on a Tuesday between 1 PM and 3 PM in Spring Quarter 2011, the Tuesday, 1 PM – 3 PM, Spring Term, and 2010/11 Academic Year indicator variables are set to ‘1’ and the rest of the variables are set to ‘0’.

2.7 Weather Variables

Weather related conditions are also of interest as possible explanatory variables. Hourly weather data are obtained from weathersource.com. These data were collected at the Ohio State University Airport, located about 5.7 miles north-west of main campus. This
is the closest location that had hourly weather data dating back to 2009. The temperature values are in degrees Fahrenheit and the precipitation values are in inches. The hourly precipitation and temperature for every school day dating back to Autumn Quarter 2009 were downloaded and copied into an Excel spreadsheet. The average of the temperature and the sum of the precipitation were calculated for the time-of-day periods for every day. These values were then matched with the data corresponding to the same date and time-of-day.

Indicator variables were created from the weather data. A variable called “Precipitation” represents any time-of-day period that had a precipitation value greater than or equal to 0.01 inches. Indicator variables for temperature were created with variables for “Below 30°F”, “Above 80°F”, and every 10° range between 30°F and 80°F. It was determined that 10° intervals would provide a sufficient number of observations for each interval, so that each interval would be well represented.
CHAPTER 3

MODEL DEVELOPMENT AND ESTIMATION

3.1 Overview

Combined route and individual route models were developed to understand the effects that service, temporal, and weather information have on intra-campus passenger flows. These models are estimated by applying Ordinary Least Squares (Linear Regression) using the program R.

Combined Route Intra-Campus models are of interest because they lead to an understanding of the overall intra-campus passenger travel on a campus-wide scale, taking into account passenger flows on multiple routes serving multiple directions within the area of interest. The combined route models include intra-campus passenger flows on four of the seven CABS bus routes. These four routes, CLN, CLS, CC, and NE, have the highest intra-campus passenger volumes of the seven routes. The individual route models are of interest because they can lead to more specific relationships at the route level and can capture possible interactions between competing routes.
It is equally interesting to examine demand in the form of intra-campus passenger volumes and the proportion of these volumes with respect to the total demand. In this chapter, models are developed considering combined routes, specific routes, volumes, and percentages.

3.2 Variable Justification

Several variables could be useful in understanding intra-campus flows on CABS buses. In this section, possible variables that may be included in models are discussed, along with their expected effects on intra-campus travel demand.

University-wide intra-campus demand is expected to increase throughout the timeframe of the study. First, the campus enrollment has increased every year since 2009, with the exception of Autumn Semester 2012. Second, a new route serving primarily the main campus bus stops was established within this timeframe. Also, the provision of traveler information has improved since Autumn Quarter 2009, and as a result, passengers now have several ways to more efficiently plan their trip. More specifically, Transportation Route Information Program (TRIP) provides users readily available real-time information regarding the locations and arrival times of all CABS buses. Users can access this information in several different ways. First, the TRIP website provides predicted bus arrival times and has a real time bus locator map that averages about 2,000 hits daily. Second, there is a texting service that provides bus arrival times at a requested stop which averages about 8,000 text messages daily and there is a cell phone application that shows
the real-time location of all the buses and also provides arrival times at bus stops. Third, digital bus arrival time boards are located at nearly every bus stop that show how many minutes until the next several buses arrive, updated in real-time.

The digital bus arrival time message boards and the cell phone application were installed and implemented at various times throughout this study’s timeframe. These applications are expected to be a factor for this increase in intra-campus travel demand because they produce instant information on bus locations and are even easier to access than the TRIP website or texting service, which existed prior to Autumn Quarter 2009. Because the digital message boards were installed over a period of time and the cell phone application came out at different dates for various cell phone brands, as well as the complexity of numerically quantifying the daily use of these information systems, there is no way to statistically analyze these technologies’ direct effects on intra-campus travel.

Academic year indicator variables are included in the models to represent the combination of increasing campus enrollment, the addition of the new CC bus route, and advances in TRIP technologies. The 2009/10 Academic Year, 2010/11 Academic Year, and 2011/12 Academic Year indicator variables are included in the model, with the 2012/13 Academic Year variable considered the reference year, an indicator variable for which is not included to avoid perfect collinearity as the academic year variables are mutually exclusive and collectively exhaustive.

In addition to the change in intra-campus demand over academic years, the change in intra-campus demand during the academic year can be evaluated by including indicator
variables for the different terms. Along with the different types of weather that occur in
these terms, the campus enrollment and passenger familiarity with CABS is different for
each term. Since the Autumn term occurs first and is when most new students begin
taking classes, they are unlikely to be familiar with the CABS routes. Also, since the
weather is pleasant in the beginning of Autumn term, students are less likely to take a
CABS bus trip rather than walk. Spring term has a smaller enrollment, but students are
more familiar with CABS after being on campus for at least two terms and possibly
taking CABS during the typically inclement Winter term. Spring term and Winter term
indicator variables are included in the regression model with the Autumn term considered
the reference quarter (to avoid perfect collinearity).

Due to class scheduling and other events occurring on campus, the passenger volumes on
a route can vary greatly within several minutes. As already discussed, in order to
eliminate the drastic changes in these demand peaks and valleys, the bus trip volumes are
aggregated into time periods that represent unique times of day. The 10 AM to 1 PM, 1
PM to 3 PM, and 3 PM to 5 PM time-of-day indicator variables are included in the
regression model, with the 8 AM to 10 AM period considered the reference time period
(to avoid perfect collinearity).

These time-of-day periods are included to examine the change in demand of intra-campus
travel in different periods of the day. As in every transit system, the travel patterns
change throughout the day. For CABS, the 8 AM to 10 AM period is known to provide a
large proportion of its service to students and staff who park at the West Campus parking
lot and travel on CABS to main campus locations. The reverse path from main campus
to the West Campus parking lot is a common passenger flow in the 1 PM to 3 PM and 3 PM to 5 PM periods. Intra-campus passenger flow is expected to be greatest during the middle of the day, when students are traveling between classes, or to activities at places like the Ohio Union, Thompson Library, workout facilities, dining halls, or dormitories.

It is known that Friday has fewer classes scheduled than the other days of the week. Therefore, there are fewer people on campus on Fridays, which is expected to result in lower ridership on CABS buses. Also, some variability may exist among the other four days of the week. Indicator variables of four of the five are considered. However, initial model estimates only support the hypothesis that Friday exhibits different demand levels. Therefore, a Friday variable is included in the models discussed subsequently.

Intra-campus travel is expected to increase as the supply of buses increase. The Bus Trips per Hour variable across all routes is considered in the combined route models. Similarly, a specific route’s Bus Trips per Hour variable is considered in the individual route models.

Precipitation is expected to increase CABS intra-campus ridership because it provides a shelter from getting wet, walking in puddles and on slippery surfaces. It is believed that the concurrence of precipitation and intra-campus travel is more important than the amount of precipitation itself, and therefore, the variable associated with rain is created as an indicator variable rather than a continuous variable. In initial model estimates, a continuous precipitation variable was considered, however, the results were inconclusive. Although precipitation may not be continuous throughout an entire time-of-day period,
data suggesting that it precipitated for some time within the period indicates that at least recent inclement weather was present. Precipitation is an indicator variable that is assigned a value of ‘1’ if there was more than 0.01 inches of precipitation during the time-of-day period.

Cold temperatures are also expected to produce higher intra-campus passenger volumes. The temperature variables are grouped in intervals because it is expected that the temperature value is not monotonically related to intra-campus flow. A monotonic relationship between temperature and intra-campus travel would indicate that as the temperature decreases the intra-campus travel on CABS increases. While this seems reasonable for cold temperatures, it is counter-intuitive under uncomfortably hot temperatures. Temporal range variables are included in the regression model with Below 30°F, ten degree intervals from 30°F to 80°F, and Above 80°F, with the 60 – 80°F interval considered the reference temperature range (again, to avoid perfect collinearity). The 60 – 70°F and 70 – 80°F variables are combined as the reference variable because almost invariable one of the two estimated coefficients of the individual variables was not statistically significant in initial model estimates.

The headway between consecutive buses on two bus routes that serve the same intra-campus bus stops is expected to have an effect on the two routes’ total intra-campus passenger demand. A passenger who has the option between multiple routes that serve his/her intra-campus OD pair will board the first bus that arrives. Therefore, if headway preceding bus arrivals on a route of interest is on average longer than the headway preceding bus arrivals on the other route, it is expected that the route of interest will have
a larger intra-campus passenger demand for those intra-campus OD pairs, assuming totally random passenger arrivals. Since the CC and Campus Loop bus routes follow a similar path for a large portion of the main campus part of the route and they share many of the same intra-campus OD pairs, passengers can choose between the two routes for many trips.

The CLS-CC Headway Ratio variable is included in the CLS and CC models. The CLN-CC Headway Ratio variable is included in the CLN and CC models. The headway ratios represent the CC headway in relation to the respective Campus Loop headway. Therefore, the headway ratio variable is expected to have a negative effect on the Campus Loop route demand and a positive effect on the CC route demand.

3.3 Intra-Campus Passengers per Hour Models

3.3.1 Combined Route Model

Combined Route Intra-Campus Passengers per Hour is an important dependent variable because it provides information on the overall demand of intra-campus passenger travel on a campus-wide scale. The Combined Route Intra-Campus Passengers per Hour Regression Model estimation results are presented in Table 2.
Table 2: Combined Route Intra-Campus Passengers per Hour Regression Model

| Explanatory Variable       | Estimate | Std. Error | t value | Pr(>|t|) |
|----------------------------|----------|------------|---------|---------|
| (Intercept)                | 91.983   | 18.079     | 5.088   | 4.03E-07|
| 2009/10 Academic Year      | -118.545 | 6.460      | -18.351 | < 2e-16 |
| 2010/11 Academic Year      | -50.932  | 5.616      | -9.070  | < 2e-16 |
| 2011/12 Academic Year      | 14.839   | 4.391      | 3.379   | 7.43E-04|
| Winter Term                | 67.498   | 4.370      | 15.445  | < 2e-16 |
| Spring Term                | 39.752   | 3.385      | 11.744  | < 2e-16 |
| 10 AM - 1 PM               | 84.391   | 3.503      | 24.091  | < 2e-16 |
| 1 - 3 PM                   | 119.503  | 3.711      | 32.203  | < 2e-16 |
| 3 - 5 PM                   | 84.763   | 3.774      | 22.462  | < 2e-16 |
| Friday                     | -40.846  | 3.115      | -13.111 | < 2e-16 |
| Bus Trips Per Hour         | 6.638    | 0.559      | 11.869  | < 2e-16 |
| Precipitation              | 50.155   | 3.787      | 13.245  | < 2e-16 |
| Below 30°F                 | 61.946   | 6.284      | 9.857   | < 2e-16 |
| 30 - 40°F                  | 51.295   | 5.070      | 10.118  | < 2e-16 |
| 40 - 50°F                  | 43.482   | 3.926      | 11.076  | < 2e-16 |
| 50 - 60°F                  | 17.091   | 3.513      | 4.865   | 1.25E-06|
| Above 80°F                 | 27.221   | 6.139      | 4.434   | 9.85E-06|

Residual standard error: 50.46 on 1661 degrees of freedom
Multiple R-squared: 0.787, Adjusted R-squared: 0.7849
F-statistic: 383.5 on 16 and 1661 DF, p-value: < 2.2e-16

The intercept value is 91.983 intra-campus passengers per hour, which corresponds to the expected demand in Autumn Semester 2012, between 8 AM and 10 AM, on a non-Friday weekday, when the temperature is between 60°F and 80°F, without precipitation, while not accounting for the effect of the Bus Trips per Hour variable. It has a t-statistic of 5.088, indicating that it is statistically different from zero (i.e., statistically significant).
The academic year variables have estimated parameter values in intra-campus passengers per hour of -118.545 for 2009/10, -50.932 for 2010/11, and +14.839 for 2011/12. These values indicate that the first academic year of the study, 2009/10, had the lowest demand for intra-campus travel on CABS. The following year, a large increase in intra-campus demand occurred, by about 67 passengers per hour. This is likely due to the addition of the CC service provided by CABS. Similarly, the 2011/12 Academic Year variable indicates an increase of intra-campus passenger volume by about 65 passengers per hour over the previous year. This is believed to be a result of students becoming more aware of the CC route’s service, passengers increasing familiarity with CABS service as a result of the TRIP technologies, as well as a continued increase in campus enrollment.

The positive value of the 2011/12 Academic Year variable indicates that there is a decrease in intra-campus demand for the 2012/13 Academic Year. This is believed to be due to the incompleteness of data from the entire 2012/13 academic year. Data is only available for the Autumn semester of the 2012/13 academic year. It is expected that Autumn terms produce the lowest intra-campus volumes due to the unfamiliarity of CABS for the new students on campus, as well as Autumn’s typically nice weather. This effect is discussed further in relation to the academic term variables. Also, the enrollment was slightly down in Autumn Semester 2012 from Autumn Quarter 2011. This was the only time when there was a decrease in enrollment from the same term of the previous year.

The Winter and Spring Term variable parameter estimates are statistically significant, having t-statistics with values of 15.445 and 11.744, respectively. The signs of both
variables are positive, meaning that the Autumn term produces less intra-campus passengers per hour than the other terms. Also, the magnitudes of the Winter and Spring Term variables are 67.498 and 39.752 intra-campus passengers per hour, respectively, indicating that the Winter term is followed by Spring term in its positive effect on intra-campus passengers per hour, with respect to the Autumn term. This is expected for several reasons. First, the Winter term has the most inclement weather and although this is partially accounted for with the weather variables, other bad weather conditions occur that might also result in travelers choosing to take CABS for intra-campus purposes. Once students become accustomed to taking intra-campus trips in the Winter term, they may continue to use CABS for similar trips in the Spring term. Also, it may still be cold in the beginning of Spring and students may form a routine of taking CABS for short trips that they continue throughout the term. Autumn term is the first term of the academic year, with many new students living around campus. They may be unfamiliar with the campus bus service and the routes it provides initially and may therefore choose to walk instead. Also, the weather is pleasant for the first few months of Autumn, and therefore, students may favor walking.

All the time-of-day variables are statistically significant, with t-statistic magnitudes of 24.091, 32.203, and 22.462, for 10 AM to 1 PM, 1 PM to 3 PM, and 3 PM to 5 PM, respectively, and their effects are therefore significantly different than that of the 8 AM to 10 AM period. The estimated parameter values are 84.391 for 10 AM to 1 PM, 119.503 for 1 PM to 3 PM, and 84.763 for 3 PM to 5 PM. Since all of the values are positive, the model indicates that the 8 AM to 10 AM period produces the least intra-campus travel.
The magnitudes of the variables indicate that the 1 PM to 3 PM period produces the highest volume of intra-campus passengers per hour, followed by 3 to 5 PM, and then 10 AM to 1 PM.

The mid-day and afternoon time periods of 10 AM to 1 PM, 1 PM to 3 PM, and 3 PM to 5 PM should intuitively have the highest intra-campus travel demand. Students may take a CABS bus within the main campus area if they have a second class in the middle of the day. Also, they may take a CABS bus to go to lunch or dinner at the Ohio Union or at various restaurants on High Street, which is only a short walk from some main campus bus stops. The 8 AM to 10 AM period is when the majority of passengers are taking CABS from their off-campus housing bus stops or West Campus parking lot stops to the main campus area for classes or work.

Fridays have a significantly lower intra-campus travel demand compared to the other days of the week with an estimated parameter value of -40.846 intra-campus passengers per hour and a t-statistic of -13.111. This is expected due to the reduced number of scheduled classes, and therefore, the presence of fewer students on campus on Fridays compared to Monday through Thursday.

The Bus Trips per Hour variable has a statistically significant estimated parameter value of 6.638, with a t-statistic of 11.869, meaning that for every additional CLS, CLN, NE, or CC bus trip per hour that is provided, 6.638 more passengers per hour use CABS for intra-campus travel. This value is expected to be positive because as service is increased, the waiting time for passengers at bus stops is decreased. This reduces the total travel
time for passengers, making it more accommodating for intra-campus travel. Also, as travelers notice more bus arrivals, they are more likely to use the bus as transportation for their short intra-campus trips.

The Precipitation variable is statistically significant with a t-statistic of 13.245 and an estimated parameter value of 50.155. This means that, on average, about 50 more intra-campus passengers per hour take CABS when it rains more than 0.01 inch within the time-of-day period. It is expected that more people would choose taking a CABS bus to reach their destination to avoid getting wet and having to walk through non-ideal conditions.

The temperature range variables have the following estimated parameter values: 61.946 for ‘Below 30°F’, 51.295 for ‘30 – 40°F’, 43.482 for ‘40 – 50°F’, 17.091 for ’50 – 60°F’, and 27.221 for ‘Above 80°F’. All of the estimates are statistically significant. The model indicates that temperatures below 30°F result in the largest intra-campus passenger volumes per hour, followed by 30 – 40°F, 40 – 50°F, Above 80°F, and 50 – 60°F. Therefore, starting from 50 – 60°F, as the temperature ranges are decreasing, the intra-campus demand increases. Also, the positive Above 80°F estimated parameter value indicates that as the temperature gets uncomfortably hot, more passengers choose CABS over walking for intra-campus travel.

The model also indicates that the temperature range of 60 – 80°F is associated with the lowest intra-campus passenger demand. This seems logical because this temperature range is considered the most comfortable, where it is not cold enough to require a jacket.
and not hot enough to be unpleasant, and therefore, many travelers may prefer to walk outside rather than take a CABS bus.

This model produced an adjusted $R^2$ value of .785, reflecting a very good fit to the data. This is the highest adjusted $R^2$ value of all the models presented. This is not surprising because this model is not subject to the inter-route differences resulting from competition between routes for passengers who could choose from several routes to serve their desired trip origin and destination. While some variables are aimed at capturing this competition in the route-specific models, it is expected that not all the effects are captured.

3.3.2 Individual Route Models

The CLS Intra-Campus Passengers per Hour Regression Model is presented in Table 3. The intercept value is -1.773 intra-campus passengers per hour, which corresponds to the expected demand in Autumn Semester 2012, between 8 AM and 10 AM, on a non-Friday weekday, when the temperature is between 60°F and 80°F, without precipitation, while not accounting for the effect of the CLS Bus Trips per Hour variable and assumes no CC buses are in service. It has a t-statistic of -0.295, indicating that it is not statistically significant.
Table 3: CLS Intra-Campus Passengers per Hour Regression Model

| Explanatory Variable | Estimate | Std. Error | t value | Pr(>|t|) |
|----------------------|----------|------------|---------|----------|
| (Intercept)          | -1.773   | 6.012      | -0.295  | 0.768    |
| 2009/10 Academic Year| -6.737   | 2.712      | -2.485  | 0.013    |
| 2010/11 Academic Year| -5.260   | 2.218      | -2.372  | 0.018    |
| 2011/12 Academic Year| -4.693   | 1.930      | -2.432  | 0.015    |
| Winter Term          | 14.967   | 1.919      | 7.798   | 1.10E-14 |
| Spring Term          | 9.928    | 1.486      | 6.682   | 3.21E-11 |
| 10 AM - 1 PM         | 30.110   | 1.530      | 19.679  | < 2e-16  |
| 1 - 3 PM             | 37.370   | 1.581      | 23.645  | < 2e-16  |
| 3 - 5 PM             | 26.329   | 1.595      | 16.504  | < 2e-16  |
| Friday               | -11.509  | 1.353      | -8.507  | < 2e-16  |
| CLS Bus Trips Per Hour| 13.409  | 0.765      | 17.530  | < 2e-16  |
| Precipitation        | 17.310   | 1.665      | 10.399  | < 2e-16  |
| Below 30°F           | 26.240   | 2.755      | 9.523   | < 2e-16  |
| 30 - 40°F            | 16.520   | 2.213      | 7.465   | 1.34E-13 |
| 40 - 50°F            | 13.759   | 1.721      | 7.996   | 2.39E-15 |
| 50 - 60°F            | 5.137    | 1.539      | 3.337   | 8.66E-04 |
| Above 80°F           | 10.521   | 2.687      | 3.915   | 9.40E-05 |
| CLS-CC Headway Ratio | 2.709    | 6.146      | 0.441   | 0.659    |

Residual standard error: 22.14 on 1660 degrees of freedom
Multiple R-squared: 0.5137,   Adjusted R-squared: 0.5087
F-statistic: 103.1 on 17 and 1660 DF,  p-value: < 2.2e-16

The Academic Year variables are negative with decreasing magnitudes as the year becomes more recent, indicating that the demand of intra-campus travel on CLS is increasing as time goes on. However, the magnitudes of the increases are small given the small differences between the estimated parameter values. One possible reason for the increase in demand is believed to be from the improvements made to TRIP. Clearly, the
CLS route intra-campus passenger volumes increase, albeit nominally, despite the addition of the CC route. A drop in demand for CLS is not present due to the introduction of CC for several reasons. First, the CC route was not widely advertised in its first year in existence, so many students on campus may not have been familiar with the route’s service. Also, the route had a lower frequency in its first year than planned, as there was a shortage of bus drivers and the CC route was the first choice of routes to be subject to a service reduction. Another reason why the CC route did not lead to a drop in demand for CLS is the presence of several other bus routes that provide northbound service for intra-campus travel similar to that of the CLS route. Four other routes serve some of the same northbound OD pairs as CLS and CC. Therefore, while the CC route is expected to affect the overall intra-campus demand, its effect on each individual route may be dampened by the presence of the other routes.

Similar to the combined route model, the Winter term produces the most intra-campus passengers per hour, followed by Spring term and Autumn term. Again, this is expected because of the inclement weather in Winter and an increase in familiarity of CABS with students as the year progresses as discussed in the Combined Route Intra-Campus Passengers per Hour Model in Section 3.3.1.

The time-of-day variables indicate that 1 PM to 3 PM produces the highest intra-campus volumes, followed by 10 AM to 1 PM, 3 PM to 5 PM, and 8 AM to 10 AM. Similar to the combined route model, 1 PM to 3 PM has the highest demand and 8 AM to 10 AM lowest demand of intra-campus travel.
The model shows that Fridays have a statistically significant lower intra-campus travel demand compared to the other days of the week with an estimated parameter value of -11.509 intra-campus passengers per hour. This is expected for the same reasons mentioned in Section 3.3.1.

The CLS Bus Trips per Hour variable has an estimated parameter value of 13.409 and it is statistically significant, indicating that as expected an increase of CLS frequency results in more intra-campus travel on CLS.

Precipitation increases intra-campus passenger demand on CLS by 17.310 passengers per hour. This is expected for the same reasons mentioned in Section 3.3.1. Temperatures below 30°F result in the largest intra-campus passenger volumes per hour, followed by 30 – 40°F, 40 – 50°F, temperatures above 80°F, and 50 – 60°F. This order is similar to that of the Combined Route Intra-Campus Passengers per Hour Model and all of the temperature range variables are statistically significant. Again, the positive Above 80°F estimated parameter value of 10.521 intra-campus passengers per hour indicates that as the temperature gets uncomfortably hot, more passengers choose CABS over walking for intra-campus travel and the fewest intra-campus trips on CLS occur when the temperature is between 60 – 80°F.

The CLS-CC Headway Ratio has an estimated parameter value of 2.709 intra-campus passengers per hour and a t-statistic of 0.441. The estimated parameter is clearly not statistically significant. As discussed in Section 3.2, this parameter is expected to be negative because as the ratio increases, the headways formed by CC buses followed by
CLS buses become relatively shorter than the headways formed by CLS buses followed by CC buses, leading to a relatively larger number of passengers boarding CC buses than CLS buses in the event where both routes serve the passengers’ OD pairs. This, in turn, would result in more intra-campus passengers for the CC route and less for the CLS route.

One reason why this value is not statistically significant may be due to other routes also serving some of the 28 intra-campus OD pairs. Some of the intra-campus OD pairs are served by the ER, NE, and BV routes. These intra-campus OD pairs can be served by as many as four routes, and thus passengers do not only have to choose between CLS and CC for some intra-campus OD pairs. This additional competition between the routes weakens any possible effect the CLS-CC Headway Ratio variable might have on the intra-campus demand on CLS.

The CLN Intra-Campus Passengers per Hour Regression Model is presented in Table 4. The intercept value is 18.378 intra-campus passengers per hour, which corresponds to expected demand in Autumn Semester 2012, between 8 AM and 10 AM, on a non-Friday weekday, when the temperature is between 60°F and 80°F, without precipitation, while not accounting for the effect of the CLN Bus Trips per Hour variable, and assuming the CC route is not in service. It has a t-statistic of 3.236, which is statistically significant.
The negative signs and decreasing magnitudes of the Academic Year variables indicate that the intra-campus passenger volumes on CLN are increasing each year. Similar to the CLS Intra-Campus Passengers per Hour Model, a decrease in intra-campus demand on CLN from the 2009/10 academic year to the 2010/11 academic year is expected due to the addition of the CC route. This result may not be present because of the low ridership
and unfamiliarity of CC during its first year. If students were unaware of the CC route, they would not take it because they would not know where it was going. There is an increase in intra-campus demand on CLN of about 24 passengers per hour from the 2010/11 academic year to the 2011/12 academic year. This is believed to be a result of the increasing enrollment between the two years, as well as the implementation of the real-time bus time arrival message boards, which were installed between those two years. The further awareness of these TRIP technologies by students is likely the reason for the continued increase in intra-campus demand on CLN which is indicated by the -8.765 intra-campus passengers per hour value for the 2011/12 Academic Year variable.

The term, time-of-day, Friday, CLN Bus Trips per Hour, and Precipitation variables reflect the same sign and similar magnitudes and patterns as seen in the CLS Intra-Campus Passengers per Hour Model.

The model shows that temperatures below 30°F result in the largest intra-campus passenger volumes per hour, followed by 30 – 40°F, 40 – 50°F, 50 – 60°F, and Above 80°F. The Above 80°F variable has a positive estimated parameter value of 0.287 intra-campus passengers per hour, although this variable is not statistically significantly different than the 60 – 80°F indicator variable. The model indicates that the fewest intra-campus trips on CLN occur when the temperature is between 60 – 80°F, similar to the other models.

The CLN-CC Headway Ratio has an estimated parameter value of -23.173 intra-campus passengers per hour and a t-statistic of -3.089. Similar to the CLS-CC Headway Ratio in
the CLS route model, the headway ratio estimated parameter value is expected to be negative because as the ratio increases, the headways formed by CC buses followed by CLN buses become relatively shorter than the headways formed by CLN buses followed by CC buses, leading to a relatively larger number of passengers boarding CC buses than CLN buses in the event where both routes serve the passengers’ OD pairs.

While the CLS-CC Headway Ratio variable is not statistically significant, the CLN-CC Headway Ratio is. This variable is believed to be statistically significant because the CLN and CC route are the only two routes competing for the southbound intra-campus travel, unlike the northbound direction which has as many as four routes serving some of the same intra-campus OD pairs.

The NE Intra-Campus Passengers per Hour Regression Model is presented in Table 5. The intercept value is -24.014 intra-campus passengers per hour, which corresponds to expected demand in Autumn Semester 2012, between 8 AM and 10 AM, on a non-Friday weekday, when the temperature is between 60°F and 80°F, without precipitation, while not accounting for the effect of the NE Bus Trips per Hour variable. It has a t-statistic of -9.297, which is statistically significant.
Table 5: NE Intra-Campus Passengers per Hour Regression Model

| Explanatory Variable | Estimate | Std. Error | t value | Pr(>|t|) |
|----------------------|----------|------------|---------|----------|
| (Intercept)          | -24.014  | 2.583      | -9.297  | < 2e-16  |
| 2009/10 Academic Year| 21.305   | 0.901      | 23.657  | < 2e-16  |
| 2010/11 Academic Year| 18.819   | 1.016      | 18.519  | < 2e-16  |
| 2011/12 Academic Year| 7.400    | 0.787      | 9.408   | < 2e-16  |
| Winter Term          | 7.082    | 0.784      | 9.039   | < 2e-16  |
| Spring Term          | 3.992    | 0.610      | 6.547   | 7.82E-11 |
| 10 AM - 1 PM         | 12.181   | 0.626      | 19.448  | < 2e-16  |
| 1 - 3 PM             | 13.007   | 0.660      | 19.706  | < 2e-16  |
| 3 - 5 PM             | 12.404   | 0.664      | 18.681  | < 2e-16  |
| Friday               | -5.635   | 0.556      | -10.141 | < 2e-16  |
| NE Bus Trips Per Hour| 2.990    | 0.206      | 14.545  | < 2e-16  |
| Precipitation        | 6.465    | 0.678      | 9.542   | < 2e-16  |
| Below 30°F           | 6.591    | 1.125      | 5.861   | 5.53E-09 |
| 30 - 40°F            | 5.898    | 0.905      | 6.513   | 9.71E-11 |
| 40 - 50°F            | 3.405    | 0.701      | 4.855   | 1.32E-06 |
| 50 - 60°F            | 1.559    | 0.628      | 2.481   | 1.32E-02 |
| Above 80°F           | 4.267    | 1.097      | 3.889   | 1.05E-04 |

Residual standard error: 9.038 on 1661 degrees of freedom
Multiple R-squared: 0.5423, Adjusted R-squared: 0.5379
F-statistic: 123 on 16 and 1661 DF, p-value: < 2.2e-16

The academic year variables have estimated parameter values in intra-campus passengers per hour of 21.305 for 2009/10, 18.819 for 2010/11, and 7.400 for 2011/12. These values indicate that the intra-campus demand is decreasing over time. The NE route is the only route model to have a continuous decrease throughout the study. One reason for the decline may be due to the closeness of all of the NE route’s main campus bus stops. Perhaps, more passengers are choosing to be more active and walk their short trip rather
than take the bus. The addition of the CC route is not expected to have an effect on the reduction of intra-campus passengers over time because these two routes serve only three similar bus stops, which results in two intra-campus OD pairs. Since there is little competition between CC and NE for intra-campus travel, a headway ratio variable was not calculated for the interaction between the two routes, as seen in the previous cases.

Another reason could be due to the effect of the BV route. The BV route shares all six of the main campus bus stops that NE serves. The BV route’s APC data was not analyzed in this thesis due to its lack of completeness, so its effect on NE cannot be analyzed. Changes in the service frequency or an increase in intra-campus travel on the BV route may be a factor in the decrease of intra-campus travel on NE. It is expected that the BV route has lower demand for intra-campus travel than NE because it has a longer trip duration and lower service frequency.

The term, time-of-day, Friday, NE Bus Trips per Hour, Precipitation, and temperature range variables reflect the same sign and similar magnitudes and patterns as seen in the CLS Intra-Campus Passengers per Hour Model.

The CC Intra-Campus Passengers per Hour Regression Model is presented in Table 6. The intercept value is -30.219 intra-campus passengers per hour, which corresponds to expected demand in Autumn Semester 2012, between 8 AM and 10 AM, on a non-Friday weekday, when the temperature is between 60°F and 80°F, without precipitation, while not accounting for the effect of the CC Bus Trips per Hour variable or the CLS-CC and CLN-CC Headway Ratio variables.
The increase in intra-campus passenger per hour volumes from the first year of the CC route’s existence to its second year was about 38 passengers per hour. This is believed to be a result of the increase in service frequency as well as the awareness of the route to its passengers. Similar to the Combined Route Intra-Campus Passengers per Hour Model, there is a slight decrease between the 2011/12 academic year and the 2012/13 academic
year and is believed to be due to the same reasons mentioned in the Combined Route model in Section 3.3.1.

The term, time-of-day, Friday, CC Bus Trips per Hour, and Precipitation variables reflect the same sign and similar magnitudes and patterns as seen in the CLS Intra-Campus Passengers per Hour Model.

The temperature variables indicate that the 60 – 80°F range produces the lowest intra-campus travel demand and that the 30 – 40°F range produces the highest intra-campus travel demand. As seen in the other models, it is expected that temperatures below 30°F produce the highest demand. Also, the model indicates that as temperatures reach above 80°F, the demand for intra-campus travel increases by a value of 16.398 passengers per hour.

The CLN-CC Headway Ratio estimated parameter value is 18.093 intra-campus passengers per hour and has a statistically significant t-statistic of 2.114. This value is expected to be positive because the variable has the opposite effect as that in the CLN Intra-Campus Passengers per Hour Model, as previously discussed in the CLN model results. For the CLN Intra-Campus Passengers per Hour Model, the estimated parameter value of the CLN-CC Headway Ratio is -23.643 intra-campus passengers per hour, which is very close in magnitude to the value in the CC Intra-Campus Passengers per Hour Model. In addition, this variable is expected to be statistically significant because CLN is the only other route that serves CC’s southbound main campus bus stops.
The CLS-CC Headway Ratio estimated parameter value is 6.083 intra-campus passengers per hour. This is not statistically significant, with a t-statistic of 0.918, similar to the same variable in the CLS Intra-Campus Passengers per Hour Model. Again, the competition between the additional northbound intra-campus serving routes weakens any possible effect the CLS-CC Headway Ratio variable might have on the intra-campus demand on CC.

3.4 Intra-Campus Percentage Models

3.4.1 Combined Route Model

Table 7 shows the results of a regression model with the dependent variable of Combined Route Intra-Campus Percentage. It is an important dependent variable because it provides information on the overall proportion of intra-campus passenger travel compared to non-intra-campus passenger travel on a campus-wide scale. Similar to the Combined Route Intra-Campus Passengers per Hour Model, it provides insight into multiple passenger flow directions, whereas some routes, like CLN, CLS, and NE, only provide unidirectional passenger flow.
Table 7: Combined Route Intra-Campus Percentage Regression Model

| Explanatory Variable       | Estimate | Std. Error | t value | Pr(>|t|)  |
|----------------------------|----------|------------|---------|-----------|
| (Intercept)                | 15.134%  | 0.0103     | 14.651  | < 2e-16   |
| 2009/10 Academic Year      | -5.368%  | 0.0037     | -14.543 | < 2e-16   |
| 2010/11 Academic Year      | -2.370%  | 0.0032     | -7.386  | 2.38E-13  |
| 2011/12 Academic Year      | 1.700%   | 0.0025     | 6.776   | 1.71E-11  |
| Winter Term                | 3.450%   | 0.0025     | 13.817  | < 2e-16   |
| Spring Term                | 4.005%   | 0.0019     | 20.706  | < 2e-16   |
| 10 AM - 1 PM               | 6.761%   | 0.0020     | 33.777  | < 2e-16   |
| 1 - 3 PM                   | 7.996%   | 0.0021     | 37.711  | < 2e-16   |
| 3 - 5 PM                   | 9.078%   | 0.0022     | 42.101  | < 2e-16   |
| Friday                     | 2.374%   | 0.0018     | 13.336  | < 2e-16   |
| Bus Trips Per Hour         | 0.142%   | 0.0003     | 4.457   | 8.87E-06  |
| Precipitation              | 2.679%   | 0.0022     | 12.383  | < 2e-16   |
| Below 30°F                 | 3.954%   | 0.0036     | 11.012  | < 2e-16   |
| 30 - 40°F                  | 3.342%   | 0.0029     | 11.536  | < 2e-16   |
| 40 - 50°F                  | 2.392%   | 0.0022     | 10.662  | < 2e-16   |
| 50 - 60°F                  | 0.702%   | 0.0020     | 3.497   | 4.84E-04  |
| Above 80°F                 | 1.620%   | 0.0035     | 4.620   | 4.14E-06  |

Residual standard error: 0.02883 on 1661 degrees of freedom
Multiple R-squared: 0.7698,   Adjusted R-squared: 0.7676
F-statistic: 347.1 on 16 and 1661 DF,  p-value: < 2.2e-16

The intercept value is 15.134%, which corresponds to the expected proportion in Autumn Semester 2012, between 8 AM and 10 AM, on a non-Friday weekday, when the temperature is between 60°F and 80°F, without precipitation, while not accounting for the effect of the Bus Trips per Hour variable. It has a t-statistic of 14.651, which indicates that the intercept is statistically significant.
The Academic Year variables have a similar trend as in the Combined Route Intra-Campus Passengers per Hour Model. The addition of the CC route and increasing campus enrollment increased the intra-campus percentage by about 3.0% from 2009/10 Academic Year to 2010/11 Academic Year. The intra-campus percentage increased by about 4.0% the following year, likely as a result of improvements made to TRIP, increasing familiarity and service of CC, and a larger campus enrollment. The 12/13 Academic Year had a slight reduction in intra-campus percentage from the previous year, by 1.7%, which is believed to be due to the incompleteness of the data from that academic year and a reduction in campus enrollment.

The Winter Term and Spring Term variables have estimated parameter values of 3.450% and 4.005%, respectively, and these estimates are statistically significant, with t-statistics of 13.817 for Winter Term and 20.706 for Spring Term. This indicates that both Winter and Spring terms have a much higher proportion of intra-campus travel than Autumn terms. Again, since Autumn is the first term of the academic year and has a large volume of new campus living students, the awareness of the CABS service is at its lowest in the academic year. Also, being the warmest term, it is expected to have the lowest proportion of intra-campus travel.

It was previously observed that the Autumn term had the lowest volumes of intra-campus passengers of the academic terms based on the Combined Route Intra-Campus Passengers per Hour Model, discussed in Chapter 3.3.1. That model also revealed that the Winter term had more intra-campus passengers per hour than the Spring term by about 28 passengers per hour. However, in the Combined Route Intra-Campus
Percentage Model, the Spring Term and Winter Term estimated parameter values are very close. This can be explained by the different effects the reduction in enrollment from Winter to Spring term has on volume and percentage demand. Typically, Autumn term has the highest enrollment, followed by Winter term, and then Spring term. The overall reduction of people on campus in the Spring term results in an equal proportion of intra-campus passenger and non-intra-campus passenger reduction. This results in the intra-campus percentage in Spring term to be very similar to that of the Winter term. However, the reduction in enrollment going from Winter to Spring does lead to a reduction in the observed volume demand.

The 10 AM – 1 PM, 1 PM – 3 PM, and 3 PM – 5 PM variables have estimated parameter values of 6.761%, 7.996%, and 9.078%, respectively. All the time-of-day variables are statistically significant. The positive signs indicate that the 8 AM to 10 AM period has the lowest proportion of intra-campus passengers of the time periods, similar to the lowest intra-campus volume produced in the Combined Route Intra-Campus Passengers per Hour Model. The magnitudes indicate that the 3 PM to 5 PM period produces the highest intra-campus proportion, followed by the 1 PM to 3 PM period, and 10 AM to 1 PM period. Aside from the 8 AM to 10 AM period having the lowest volume and proportion of intra-campus travel, the other time periods do not reflect similar time-of-day patterns considering volume and percentage demand. It is believed that the largest amount of people that come to campus and park in the West Campus parking lot arrive between the hours of 8 AM and 10 AM, as the majority of classes are scheduled in the morning and mid-day and, therefore, the proportion of non-intra-campus travel is very
high in that period. The distribution of the departure times of travelers who park at West Campus on their return trips to West Campus is much more varied. This may depend on the individual’s number of classes for the day and the time of their final class or meeting of the day.

The Friday variable has an estimated parameter value of 2.374% and is statistically significant with a t-statistic of 13.336, meaning that Fridays have a higher proportion of CABS usage for intra-campus travel than the other days of the week. It is known that the overall volume of passengers that use CABS on Fridays is less than the other days of the week, but this indicates that the intra-campus passenger volumes do not decrease at the same rate as the non-intra-campus passengers. While there may be less overall travel on campus on Fridays to get to classes, people who live on or near campus may still be taking CABS for intra-campus trips to recreation centers, restaurants, or the Ohio Union at the same rate as the other days of the week.

The Bus Trips per Hour variable has an estimated parameter value of 0.142%, indicating that for every CLN, CLS, NE, and CC trip that occurs per hour, the intra-campus travel proportion increases by 0.142%. The Bus Trips per Hour variable is statistically significant, with a t-statistic of 4.457. Due to the long distance of a non-intra-campus passenger trips, taking a bus for these trips is considered a requirement. Therefore, the service frequency for these passengers would not affect the demand of passengers using CABS for non-intra-campus travel. However, since intra-campus travel is considered a convenience, the more service available, the more likely the demand increases for intra-campus travel on CABS. This means, as the service frequency increases, the number of
intra-campus travelers increase, while the number of non-intra-campus travelers remains the same, and therefore, the proportion of intra-campus travel increases.

The Precipitation variable has an estimated parameter value of 2.679%, indicating that the intra-campus passenger proportion increases if it precipitated more than 0.01 inches in the time interval. The Precipitation variable is statistically significant with a t-statistic of 12.383. Since the non-intra-campus trips are considered required, precipitation is not expected to change the demand for those passengers. As seen in the Combined Route Intra-Campus Passengers per Hour Model, the Precipitation variable produces a positive estimated parameter value, indicating an increase in intra-campus volume, and thus the increase in the proportion of intra-campus travel is expected.

The temperature range variables are all statistically significant and have the following estimated parameter values: 3.954% for ‘Below 30°F’, 3.342% for ‘30 – 40°F’, 2.342% for ‘40 – 50°F’, 0.702% for ‘50 – 60°F’, and 1.620% for ‘Above 80°F’. The order of the magnitudes is similar to the Combined Route Intra-Campus Passengers per Hour Model which indicates that the temperature range of 60 – 80°F produces the lowest proportion of intra-campus passengers and the intra-campus percentage is increased once the temperature is above 80°F. The model also shows that the lower the temperature, the higher the proportion of CABS usage is for intra-campus travel, until the temperature is 60 – 80°F. These results seem logical because the temperature is not expected to change the demand of non-intra-campus travel.
This model produced an adjusted $R^2$ value of .7676, reflecting a very good fit to the data. This model has the highest adjusted $R^2$ of the intra-campus percentage models. This is not surprising because this model is not subject to inter-route differences resulting from competition between routes for passengers who could choose between multiple routes to take their intra-campus trip, rendering the relationship more complex when considering route-specific models.

**3.4.2 Individual Route Models**

The CLS Intra-Campus Percentage Regression Model is presented in Table 8. The intercept value is 25.082%, which corresponds to the expected proportion in Autumn Semester 2012, between 8 AM and 10 AM, on a non-Friday weekday, when the temperature is between 60°F and 80°F, without precipitation, while not including the effect of the CLS Bus Trips per Hour variable, and assuming that there are no CC buses in service. It has a t-statistic of 19.61, which indicates the intercept is statistically significant.
Table 8: CLS Intra-Campus Percentage Regression Model

| Explanatory Variable          | Estimate | Std. Error | t value | Pr(>|t|) |
|------------------------------|----------|------------|---------|----------|
| (Intercept)                  | 25.082%  | 0.0128     | 19.610  | < 2e-16  |
| 2009/10 Academic Year        | -0.821%  | 0.0058     | -1.423  | 0.1549   |
| 2010/11 Academic Year        | -3.204%  | 0.0047     | -6.789  | 1.56E-11 |
| 2011/12 Academic Year        | -0.615%  | 0.0041     | -1.497  | 0.1346   |
| Winter Term                  | 4.600%   | 0.0041     | 11.266  | < 2e-16  |
| Spring Term                  | 5.304%   | 0.0032     | 16.778  | < 2e-16  |
| 10 AM - 1 PM                 | 6.626%   | 0.0033     | 20.353  | < 2e-16  |
| 1 - 3 PM                     | 7.206%   | 0.0034     | 21.430  | < 2e-16  |
| 3 - 5 PM                     | 7.841%   | 0.0034     | 23.101  | < 2e-16  |
| Friday                       | 1.930%   | 0.0029     | 6.707   | 2.72E-11 |
| CLS Bus Trips Per Hour       | 0.256%   | 0.0016     | 1.575   | 0.1154   |
| Precipitation                | 3.476%   | 0.0035     | 9.814   | < 2e-16  |
| Below 30°F                   | 6.535%   | 0.0059     | 11.148  | < 2e-16  |
| 30 - 40°F                    | 4.369%   | 0.0047     | 9.280   | < 2e-16  |
| 40 - 50°F                    | 4.055%   | 0.0037     | 11.074  | < 2e-16  |
| 50 - 60°F                    | 1.585%   | 0.0033     | 4.839   | 1.43E-06 |
| Above 80°F                   | 1.205%   | 0.0057     | 2.107   | 3.52E-02 |
| CLS-CC Headway Ratio         | -1.816%  | 0.0131     | -1.389  | 0.1652   |

Residual standard error: 0.0471 on 1660 degrees of freedom
Multiple R-squared: 0.5143,    Adjusted R-squared: 0.5094
F-statistic: 103.4 on 17 and 1660 DF,  p-value: < 2.2e-16

The only Academic Year variable that is significant is the 2010/11 Academic Year. That is, the contributions of the 2009/10 and 2011/12 Academic Year variables are not statistically significantly different from that of the 2012/13 Academic Year variable. The lower intra-campus percentage on CLS for the 2010/11 Academic Year with respect to the 2009/10 Academic Year is believed to be a result of the introduction of CC, although
this trend is not seen in the CLS Intra-Campus Passengers per Hour Model. The lower intra-campus percentage on CLS for the 2010/11 Academic Year with respect to the 2011/12 Academic Year and 2012/13 Academic Year is believed to be a result of the improvements of TRIP services and increasing campus enrollment.

The Winter Term and Spring Term variables have estimated parameter values of 4.600% and 5.340%, respectively. Similar to the Combined Route Intra-Campus Percentage Model, this indicates that both Winter term and Spring term have a much higher proportion of intra-campus travel than Autumn term. This is expected for the same reasons as described in the combined route model in Section 3.4.1.

The 3 PM to 5 PM variable has the highest proportion of intra-campus passengers, followed by 1 PM to 3 PM, 10 AM to 1 PM, and 8 AM to 10 AM. This is similar to the Combined Route Intra-Campus Percentage Model, as well as the other individual route intra-campus percentage models to follow. The proportion of non-intra-campus travel is expected to be very high in the 8 AM to 10 AM period due to the arrival of many students at the West Campus parking lot who need transportation to main campus. These arrivals are expected to decrease as the day goes on. The departures from campus are expected to be more evenly distributed over the 10 AM to 5 PM period, depending on the students remaining daily schedule. These travel patterns, with the knowledge of the higher demand of intra-campus travel in afternoon periods seen in the Intra-Campus Passengers per Hour models, is believed to be why the intra-campus proportion of travel increases as the day goes on. Since all three of the individual route Intra-Campus
Percentage models represent routes that travel to the West Campus parking lot, this trend is expected to be the same for each.

The Friday variable has an estimated parameter value of 1.930%, indicating that Fridays have a higher proportion of intra-campus travel than the other days of the week. This is similar to the Combined Route Intra-Campus Percentage Model and is believed to be due to the same reasons mentioned in Section 3.4.1.

The CLS Bus Trips per Hour variable has an estimated parameter value of 0.256% with a t-statistic of 1.575. The t-statistic indicates that the frequency of CLS buses is not a statistically significant factor in the proportion of intra-campus passengers taking the CLS bus route.

The Precipitation variable has an estimated parameter value of 3.476%, indicating that the proportion of intra-campus travel is increased on all routes when there is precipitation within the time interval. This is similar to the Combined Route Intra-Campus Percentage Model and is believed to be due to the same reasons mentioned in Section 3.4.1.

The model shows that temperatures below 30°F result in the largest intra-campus percentage, followed by 30 – 40°F, 40 – 50°F, 50 – 60°F, and temperatures above 80°F. The Above 80°F variable has a positive estimated parameter value of 1.205%, indicating that the intra-campus percentage increases when it gets uncomfortably hot. The model indicates that the fewest intra-campus trips on CLS occur when the temperature is between 60 – 80°F, similar to the combined route model.
Similar to the CLS and CC Intra-Campus Passengers per Hour Models, the CLS-CC Headway Ratio variable is not statistically significant in this model. Again, the competition between the additional northbound intra-campus serving routes weakens any possible effect the CLS-CC Headway Ratio variable might have on the intra-campus percentage on CLS.

The CLN Intra-Campus Percentage Regression Model is presented in Table 9. The intercept value is 23.872%, which corresponds to the expected demand in Autumn Semester 2012, between 8 AM and 10 AM, on a non-Friday weekday, when the temperature is between 60°F and 80°F, without precipitation, while, not including the effects of the Bus Trips per Hour variable, and assuming that there are no CC buses in service. It has a t-statistic of 20.530, which indicates the intercept is statistically significant.
The decrease in intra-campus percentage from the 2009/10 Academic Year to the 2010/11 Academic is believed to be a result of the introduction of the CC route, although this trend is not seen in the CLN Intra-Campus Passengers per Hour Model. The higher intra-campus percentage on CLN from the 2011/12 Academic Year with respect to the 2010/11 Academic Year is believed to be a result of the improvements made to TRIP and

### Table 9: CLN Intra-Campus Percentage Regression Model

| Explanatory Variable                  | Estimate | Std. Error | t value | Pr(>|t|) |
|---------------------------------------|----------|------------|---------|----------|
| (Intercept)                           | 23.872%  | 0.0116     | 20.530  | < 2e-16  |
| 2009/10 Academic Year                 | -7.432%  | 0.0061     | -12.145 | < 2e-16  |
| 2010/11 Academic Year                 | -7.852%  | 0.0041     | -19.089 | < 2e-16  |
| 2011/12 Academic Year                 | -2.225%  | 0.0039     | -5.663  | 1.75E-08 |
| Winter Term                           | 3.235%   | 0.0039     | 8.280   | 2.50E-16 |
| Spring Term                           | 2.908%   | 0.0031     | 9.437   | < 2e-16  |
| 10 AM - 1 PM                          | 9.939%   | 0.0031     | 31.850  | < 2e-16  |
| 1 - 3 PM                              | 12.627%  | 0.0032     | 38.954  | < 2e-16  |
| 3 - 5 PM                              | 14.348%  | 0.0033     | 43.359  | < 2e-16  |
| Friday                                | 3.013%   | 0.0027     | 10.992  | < 2e-16  |
| CLN Bus Trips Per Hour                | -0.220%  | 0.0013     | -1.640  | 0.10117  |
| Precipitation                         | 2.921%   | 0.0034     | 8.694   | < 2e-16  |
| Below 30°F                            | 4.960%   | 0.0056     | 8.867   | < 2e-16  |
| 30 - 40°F                             | 4.218%   | 0.0045     | 9.354   | < 2e-16  |
| 40 - 50°F                             | 3.670%   | 0.0035     | 10.507  | < 2e-16  |
| 50 - 60°F                             | 1.560%   | 0.0031     | 5.002   | 6.27E-07 |
| Above 80°F                            | 0.025%   | 0.0055     | 0.045   | 9.64E-01 |
| CLN-CC Headway Ratio                  | -4.615%  | 0.0157     | -2.945  | 0.00328  |

Residual standard error: 0.04478 on 1660 degrees of freedom  
Multiple R-squared: 0.676,      Adjusted R-squared: 0.6727  
F-statistic: 203.8 on 17 and 1660 DF,  p-value: < 2.2e-16
increasing campus enrollment. The further awareness of TRIP by students is likely the reason for the continued increase in intra-campus demand on CLN which is indicated by the -2.225% value for the 2011/12 Academic Year variable.

The term, time-of-day, Friday, CLN Bus Trips per Hour, and Precipitation variables reflect the same sign and similar magnitudes and patterns as seen in the CLS Intra-Campus Percentage Model.

The model shows that temperatures below 30°F result in the largest intra-campus percentage, followed by 30 – 40°F, 40 – 50°F, 50 – 60°F, and temperatures above 80°F. The Above 80°F variable has a positive estimated parameter value of 0.025%, although this is not statistically significant compared to the 60 – 80°F variable. The Above 80°F indicator variable is also not statistically significant in the CLN Intra-Campus Passengers per Hour Model. The model indicates that the fewest intra-campus trips on CLN occur when the temperature is between 60 – 80°F, similar to all the previous models.

The CLN-CC Headway Ratio is statistically significant with a t-statistic of -2.945 and an estimated parameter value of -4.615%. Similar to the CLN-CC Headway Ratio in the CLN Intra-Campus Passengers per Hour Model, the headway ratio estimated parameter value is expected to be negative because as the ratio increases, the headways formed by CC buses followed by CLN buses become relatively shorter than the headways formed by CLN buses followed by CC buses, leading to a relatively larger number of passengers boarding CC buses than CLN buses in the event where both routes serve the passengers’ OD pairs.
This variable is believed to be statistically significant because the CLN and CC route are the only two routes competing for the southbound intra-campus travel, unlike the northbound direction which has as many as four routes serving some of the same intra-campus OD pairs.

The NE Intra-Campus Percentage Regression Model is presented in Table 10. The intercept value is -2.926%, which corresponds to the expected demand in Autumn Semester 2012, between 8 AM and 10 AM, on a non-Friday weekday, when the temperature was between 60°F and 80°F, without precipitation. It has a t-statistic magnitude of 4.131, which indicates the intercept is statistically significant.
**Table 10: NE Intra-Campus Percentage Regression Model**

| Explanatory Variable        | Estimate | Std. Error | t value | Pr(>|t|) |
|----------------------------|----------|------------|---------|----------|
| (Intercept)                 | -2.926%  | 0.0071     | -4.131  | 3.79E-05 |
| 2009/10 Academic Year       | 5.353%   | 0.0025     | 21.151  | < 2e-16  |
| 2010/11 Academic Year       | 3.349%   | 0.0022     | 15.220  | < 2e-16  |
| 2011/12 Academic Year       | 1.820%   | 0.0017     | 10.578  | < 2e-16  |
| Winter Term                 | 1.122%   | 0.0017     | 6.552   | 7.57E-11 |
| Spring Term                 | 1.685%   | 0.0013     | 12.704  | < 2e-16  |
| 10 AM - 1 PM                | 2.479%   | 0.0014     | 18.065  | < 2e-16  |
| 1 - 3 PM                    | 2.977%   | 0.0015     | 20.476  | < 2e-16  |
| 3 - 5 PM                    | 4.208%   | 0.0015     | 28.465  | < 2e-16  |
| Friday                      | 0.603%   | 0.0012     | 4.940   | 8.61E-07 |
| NE Bus Trips Per Hour       | 0.142%   | 0.0002     | 6.487   | 1.15E-10 |
| Precipitation               | 1.498%   | 0.0015     | 10.101  | < 2e-16  |
| Below 30°F                  | 1.099%   | 0.0025     | 4.466   | 8.52E-06 |
| 30 - 40°F                   | 1.020%   | 0.0020     | 5.138   | 3.11E-07 |
| 40 - 50°F                   | 0.452%   | 0.0015     | 2.942   | 3.31E-03 |
| 50 - 60°F                   | -0.075%  | 0.0014     | -0.549  | 5.83E-01 |
| Above 80°F                  | 1.347%   | 0.0024     | 5.600   | 2.50E-08 |

Residual standard error: 0.01977 on 1661 degrees of freedom
Multiple R-squared: 0.6015, Adjusted R-squared: 0.5977
F-statistic: 156.7 on 16 and 1661 DF, p-value: < 2.2e-16

The Academic Year indicator variables are positive and decreasing in magnitude, indicating a decrease in the proportion of intra-campus travel to non-intra-campus travel on NE. This is similar to the pattern seen in the NE Intra-Campus Passengers per Hour Model described in Section 3.3.2 and may be a result of changes in service on the BV route or travelers choosing to be more active and walk their short trip, since NE serves a small area of main campus.

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The NE Intra-Campus Percentage Model is the only individual route intra-campus percentage model that has a statistically significant bus trips per hour variable. The model indicates that for each NE bus trip per hour, the intra-campus percentage increases by 0.142%.

The term, time-of-day, Friday, and Precipitation variables reflect the same sign and similar magnitudes and patterns as seen in the CLS Intra-Campus Percentage Model.

The temperature range variables indicate that highest proportion of intra-campus travel occurs when the temperature is above 80°F. In every other model, the cold temperature range variables resulted in the highest demand and percentages. Temperatures below 30°F produce the second highest proportion, followed by each warmer temperature range until the temperature gets to the 60 – 80°F range. The temperature range of 50 – 60°F produces the lowest proportion of intra-campus travel, although this variable is not statistically significant compared to the reference 60 – 80°F variable.
CHAPTER 4

CONCLUSIONS AND FUTURE RESEARCH

4.1 Conclusions

This study demonstrated that models can capture relationships of interest between multiple explanatory variables and short trips where walking is a viable alternative, as represented by intra-campus demand on the OSU campus. Multiple models were estimated to allow an examination of intra-campus demand at the level of an individual route and at the campus-wide level, both in terms of intra-campus volume and intra-campus proportion. Considering results from both volume and proportion models allows for a greater understanding of factors affecting intra-campus demand than if only a volume or proportion model had been considered.

In addition, observing similar patterns across different models supports the validity of the relationships. The precipitation and temperature variables are examples of variables that show similar effects on intra-campus demand across all models. Precipitation increases intra-campus passenger volume and the proportion of intra-campus passenger ridership in all the models developed. Precipitation is expected to increase CABS intra-campus
ridership because it provides a shelter from the negative effects of precipitation that would be encountered if choosing the competing walking alternative. The effect would also be seen as an increase in the intra-campus proportion because there is expected to be little competition from the walking mode for the non-intra-campus cells of the OD matrix.

Very low or very high temperatures also increase intra-campus passenger volume and proportion. It was found that the 60°F to 80°F temperature range produces the lowest intra-campus travel demand on CABS. This seems logical because this temperature range is considered comfortable, where it is not cold enough to require a jacket and not hot enough to be unpleasant. In this range, many travelers may prefer to walk outside rather than take a CABS bus. The models show that temperatures below 30°F result in the largest intra-campus passenger demand, with the demand decreasing as the temperature increases until the 60°F to 80°F range, meaning that as the temperature gets warmer, fewer passengers take CABS for intra-campus trips. When temperatures are above 80°F, demand for intra-campus CABS trips again increase. Again, because there is little competition from walking for non-intra-campus trips, temperature would affect volumes more on intra-campus trips than on non-intra-campus trips, resulting in both higher volumes and higher proportions for intra-campus trips.

Other variables, for example the day-of-week and time-of-day indicator variables, show different effects in the volume models than in the percentage models. The models indicate that the highest intra-campus passenger volumes occur between 10 AM and 1 PM. This is expected because this is the time of the day when campus appears to be most
populated. On the other hand, the intra-campus percentage models indicate that the 3 PM to 5 PM period has the highest proportion of passengers using CABS for intra-campus trips, followed by 1 PM to 3 PM, and then 10 AM to 1 PM. Although the highest volume of intra-campus passengers occurs during the 10 AM to 1 PM period, the larger volume of non-intra-campus passengers present during that time makes the proportion lower than in the other time-of-day periods. The comparison of the volume and proportion model results also indicates that campus volumes decrease throughout the day at a higher rate than the intra-campus passenger volumes, which results in greater intra-campus proportions as the day goes on. This indication is consistent with the observation (based on familiarity with campus travel patterns) of large, park-and-ride (non-intra-campus) bus flows in the morning.

The intra-campus passengers per hour models show that Friday has the lowest intra-campus volume of all the days of the week. Fridays also result in the highest intra-campus proportion of CABS ridership of all the days of the week, as seen in the intra-campus percentage models. While there may be less overall travel on campus on Fridays to get to classes, people who live on or near campus may still be taking CABS for intra-campus trips to rec centers, restaurants, or the Ohio Union at roughly the same rate as the other days of the week. In addition, it is possible that the proportion of students who attend class on Friday is greater among students who live on or near campus than among students who live far away from campus.

Variables that represent interactions between multiple routes can also be a factor in explaining intra-campus demand for the individual routes. The CLS-CC Headway Ratio
and CLN-CC Headway Ratio variables are examples of variables that provide information on interactions between multiple routes. The effect of the CLN-CC Headway Ratio variable on intra-campus bus flows in the CLN and CC models indicates that the nature of the inter-route headways considering routes that share a similar alignment has a statistically significant effect on intra-campus demand on both routes. On the other hand, on alignments served by multiple routes, the effect of the headway ratio between two routes is not a statistically significant factor in intra-campus travel on either route, as seen in the CLS and CC models with the CLS-CC Headway Ratio variable.

The magnitude and significance of the academic year variables indicate that the demand of intra-campus travel using CABS has increased over the study for all routes except NE. The increase is believed to be due to the increasing enrollment, the addition of the CC service, and the implementation of new TRIP technologies. These factors are believed to affect each route differently, which is why the academic year variable magnitudes and patterns are not consistent across different routes.

4.2 Future Research

Although interesting results have already been arrived at, this study motivates future related research. Continuing to collect the passenger boarding and alighting counts using APCs would enable the continued examination of how the intra-campus passenger demand on CABS is changing. It would be interesting to observe how the intra-campus
demand is changing as travelers on campus become more familiar with the TRIP technologies and as the university transitions from quarters to semesters.

Including data for all of the routes on campus would give a more precise evaluation of overall intra-campus demand campus-wide. In this study, data from the CLS, CLN, CC, and NE routes were used, but data from the ER, BV, and MC routes were not included. The routes chosen for this study are the major CABS routes in terms of passenger volumes, but it would be interesting to investigate if some different factors affect the demand on the other routes.

Considering more variables that represent interactions between multiple routes may help produce better models. For example, considering a headway ratio variable between the NE and CC route at the three bus stops served by both routes would allow an investigation of the relationship between NE and CC.

Finally, it would be interesting to develop demand models similar to those developed in this study with city-wide agency data and to compare the results to those found in this study. City-wide agencies would not have “intra-campus” trips, but may have a large demand for “intra-downtown” trips, where passengers could consider walking or taking a taxi to their destination as alternatives. Unlike CABS, city transit agencies typically have a cost to ride associated with their service. In addition, the financial status of people in an urban downtown setting would be much different than that of students on campus. Safety might also be a more significant factor in an urban setting than a college campus. It would be interesting to study how these differences effect demand of short bus trips.
REFERENCES


Figure 4: 2009 – 2010 Academic Year CABS Route Map
Figure 5: 2010 – 2011 Academic Year CABS Route Map
Figure 6: 2011 – 2012 Academic Year CABS Route Map