SPATIAL DISTRIBUTION OF PARK-AND-RIDE DEMAND

by

Du Zhang

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

Fall 2014

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SPATIAL DISTRIBUTION OF PARK-AND-RIDE DEMAND

by

Du Zhang

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I would also like to thank dozens of people without whose help this thesis cannot be finished. Specially I would like to thank Catherine C Smith, Henderson Wayne, Mitchell Ivan, and Bernard Au from Delaware Transit Corporation, Delaware Department of Transportation, for their collaborations in this project.

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At the end I would like to express my appreciation to my beloved wife Yuan He for her love, support, encouragement, and sacrifices along the last and my best ten years.
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ABSTRACT

Park-and-ride facilities have been effective hubs that connect private transportation options and public transit systems such as buses and trains. Because of their long construction and service time, accurate prediction about their usages is of the utmost importance because it is not only crucial for location and capacity decisions, but will also influence public images of transportation agencies if anything goes wrong.

Reasonable description about park-and-ride demand spatial distribution is a critical part in its demand prediction. Previous researchers usually use catchment areas covering majority park-and-ride demand and assume uniform distribution within the catchment area. This leads to arbitrary choice of shape and size of catchment areas. It also does not allow for overlapped catchment areas which are very common in practice.

This paper develops separate models for train-based and bus-based park-and-ride systems because of their different utilization patterns. More specifically, a combination of gravity model and mode choice model is proposed to describe train-based park-and-ride system, while Tobit model is used in bus-based system. Both models can be viewed as generalizations of catchment areas - different parameters will generate different sizes and shapes of catchment areas. They also allow for overlaps of different catchment areas. Empirical tests in Delaware show these two models have very good in-sample predictions as well.
Chapter 1

INTRODUCTION

Park-and-ride facilities have been effective hubs that connect private transportation options (cars) and public transit systems such as buses and trains. They play an important role in alleviating traffic congestion and pollution by encouraging people to use public transit systems.

Demands (usages) of park-and-rides are driven by the needs from the local residential developments. For example, the rapid growth of retirement communities in Delaware will lead to expanded usages of many park and rides. On the other hand, demands for these facilities are also induced by remote attractions on the public transit lines served by the facility. The recent significant attraction developments inside or nearby Delaware, such as the expansion of Christiana Mall, the military base reallocation to APG, and the University of Delawares acquisition of the Chrysler plant and subsequent development, will inevitably alter the transit traffic patterns and lead to more demands of affected park-and-ride facilities. Furthermore, based on our current field study, many park-and-ride facilities, especially those near the train stations are already congested and out of capacity. Due to its relatively long investment and construction time, there is a need for a careful forecast of the demand for each park-and-ride facility based on existing and potential developments prior to any plan of expanding the facility.

Unfortunately, there has been very little research on this topic from academic literature. Our research project filled the gap by creating an accurate and easy to use demand forecast model for both bus and train based park and ride facilities.

Our demand forecast model for train based park and rides combines the gravity sub-model that calculates potential total demand and the mode choice sub-model that
describes the commuters transportation mode selection. The model is then calibrated by the park and ride usage data collected. The combined model fits the existing usage significantly better than the traditional linear model. The bus based demand forecast model uses the Tobit model, which is an improvement over the traditional linear regression model as well.

Both models are very easy to use and have been implemented via Excel spreadsheet. A user only needs to input the location of a potential residential development and the estimated number of occupants in the development. The models will output the resulting demand increases in all park and ride facilities impacted by the development. The goal of this paper is to set up a spatial distribution model for park and ride facilities.

1.1 Literature Review

Park and ride facilities emerged in Europe as a response to the 1970s energy crisis. They enable transportation agencies to address issues with congestion and pollution by encouraging transit ridership and reducing auto trips. Various studies have found that although park and ride systems may not be as helpful as expected in alleviating traffic congestion (partly because of increasing traffic in general), they have successfully attracted people switching from automobiles and other modes [20, 22]. In additional to traffic benefits, park and ride system will also yield environmental benefits [21].

Since then, park and ride facilities have spread rapidly around the world especially in Europe, North America and Asian: London and South East, UK [18], Scotland [6], United States [19, 28], Calgary, Canada [2], Singapore [27], and East Asia [14].

Initial researches mainly focused on general guidelines for park and ride systems: [5], [7], [17], [25], and [29]. Besides these general guidelines, there are also some literature specifically for rail-based park and ride system. [8, 2]

Because park-and-ride facilities are usually permanent and cost a lot of money, it is quite important for transportation agencies to carefully locate them. Many different
frameworks have been proposed for this purpose: [9] used a hybrid system of knowledge-based expert system and geographic information system to help determine the best location for potential park and ride facilities; [3] conducted a hierarchical choice experiment in Nijmegen, The Netherlands; [31] constructed a model with deterministic mode choice in a linear monocentric city; [10] developed multi-objective spatial optimization model for facility location.

Besides location, it should also be essential to accurately forecast the demand because the accuracy of demand estimation not only have a great impact on their cost structures but also will influence their public images [29]. Some forecasting models are built upon individual level survey data: [3, 24], while some use mathematical models to capture the demand distribution: [11, 1, 15]. Our paper will follow the second path.

Many papers above adopted catchment area, the area from which park and ride facilities attract users, as their building blocks when forecasting park and ride demand. However, there’s still no consensus about shapes and extents of catchment areas. Different forms of catchment areas have been employed before in literature:

- Circular: [4] defined a circular 2.5-mile radius area centered on park and ride facility as its catchment area.

- Offset circular: [29] also uses a circular catchment area but suggested an offset center point for park and ride facilities (See Figure 1.1).

- Ellipse: Both [25] and [29] suggested ellipses as shape of park and ride facility (See Figure 1.2).

- Parabola: parabola park and ride catchment areas are very popular in literature: [17], [8] (See Figure 1.3), [29] (See Figure 1.4), and [16] (See Figure 1.5).

- Other shapes of park and ride catchment areas include cone shape suggested by [13] and pear shape by [7].
Figure 1.1: Offset Circular Catchment Area in [29]

Figure 1.2: Ellipsoidal Catchment Area in [29]
Figure 1.3: Parabola Catchment Area in [8]

Figure 1.4: Parabola Catchment Area in [29]

Figure 1.5: Parabola Catchment Area in [16]
Chapter 2

PARK AND RIDE SYSTEMS IN DELAWARE

The purpose of this chapter is to provide an overview of park and ride systems in Delaware.

2.1 Basic Information

Park and ride systems in Delaware are run by DART First State, or Delaware Transit Corporation (DTC), an operating division of the Delaware Department of Transportation. DART is also in charge of other public transit systems such as fixed route bus routes, trains, and paratransit services. DART is majorly funded by State and Federal governments.

Delaware has 37 park and ride lots, of which 31 are located in New Castle County, 5 in Kent County, and 1 in Sussex County. In addition, there are 12 park and pool lots here in Delaware, half of them in New Castle County, a quarter in Kent County, and the rest in Sussex County.

See below for a list and map of these park and rides, as well as park and pools directly from DART’s website. Note that this list may have been updated.
DART First State Park & Ride/Park & Pool Lots
Effective June 21, 2009

Park & Rides - Lots are available throughout the State to park your car and ride transit or meet a carpool or vanpool. The specific transit routes serving each location are listed. Circled numbers correspond to map locations (see back side).

**NEW CASTLE COUNTY**

<table>
<thead>
<tr>
<th>Location</th>
<th>Address</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Claymont Overflow Parking</td>
<td>Governor Printz Blvd. at Pedestrian Walkway</td>
<td>Train Rt: SEPTA R2</td>
</tr>
<tr>
<td>Claymont Train Station</td>
<td>41 Myrtle Ave.</td>
<td>Train Rt: 1, 61/Train Rt: SEPTA R2</td>
</tr>
<tr>
<td>Tri-State Mall</td>
<td>1-95 and Naamans Rd.</td>
<td>Bus Rts: 1, 61, SEPTA Rt 113</td>
</tr>
<tr>
<td>Naamans &amp; Carpenter Roads</td>
<td>Wilmington - Bus Rts: 21, 61</td>
<td>(Board on Naamans Rd.)</td>
</tr>
<tr>
<td>Trinity Presbyterian Church</td>
<td>1120 Darley Rd.</td>
<td>Bus Rts: 21, 61</td>
</tr>
<tr>
<td>Faith Presbyterian Church</td>
<td>700 Marsh Road</td>
<td>Bus Rts: 11, 38</td>
</tr>
<tr>
<td>Concord Presbyterian Church</td>
<td>1800 Fairfax Boulevard</td>
<td>Bus Rts: 21</td>
</tr>
<tr>
<td>Aldersgate United Methodist Church</td>
<td>2313 Concord Pike</td>
<td>Bus Rts: 2, 35</td>
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<tr>
<td>Lutheran Church of the Good Shepherd</td>
<td>1530 Folks Road</td>
<td>Bus Rts: 21</td>
</tr>
<tr>
<td>North Baptist Church</td>
<td>3318 Silverside Road</td>
<td>Bus Rts: 35</td>
</tr>
<tr>
<td>Brandywine Town Center</td>
<td>Concord Pike &amp; Naamans Rd.</td>
<td>Bus Rts: 2, 35, 61, SEPTA Rt 306</td>
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<td>Lower Brandywine Presbyterian Church</td>
<td>101 Old Kennett Rd.</td>
<td>Bus Rts: 10</td>
</tr>
<tr>
<td>RCCSD – DE 52 &amp; DE 100 (DuPont Rd.)</td>
<td>Wilmington - Bus Rts: 10, 20</td>
<td>(Board on DE 52)</td>
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**GERMANY DRIVE**

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<tr>
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<tr>
<td>402 North Maryland Ave.</td>
<td>Wilmington - Bus Rts: 5, 9</td>
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**WACHOVIA BANK**

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<th>Notes</th>
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<tr>
<td>DE 41, New Lancaster Pike</td>
<td>Hockessin - Bus Rts: 20 (board at bus shelter)</td>
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**Hockessin Memorial Hall**

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<th>Notes</th>
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<tr>
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<td>Hockessin - Bus Rts: 20</td>
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**FAITH BAPTIST CHURCH**

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<tr>
<td>4210 Limestone Road</td>
<td>Wilmington - Bus Rts: 19, 30</td>
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**SKYLINE UNITED METHODIST CHURCH**

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<tr>
<td>Skyline Dr. &amp; Linden Hill Rd.</td>
<td>Wilmington - Bus Rts: 19</td>
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**Fairplay Station at Churchmans Crossing**

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<tr>
<td>1 Fairplay Blvd.</td>
<td>Train Rts: SEPTA R2</td>
</tr>
<tr>
<td>Newark - Bus Rts: 5, 33, 59, 62, 63</td>
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**Prices Corner**

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<td>Centerville Rd.</td>
<td>Bus Rts: 6, 9, 19, 36</td>
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**Newark Train Station**

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<tr>
<td>Mopar Dr., Newark</td>
<td>Train Rts: SEPTA R2, Amtrak</td>
</tr>
<tr>
<td>Bus Rts: 16, 33, 39 (Board on S. Collage Ave.)</td>
<td>59, 65</td>
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**Scottfield (Brookside)**

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<td>DE 72 &amp; Chestnut Hill Rd.</td>
<td>Newark - Bus Rts: 33, 55</td>
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**DE 896 & DE 4**

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<td>Newark - Bus Rts: 16, 33, 39, 59, 65</td>
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**Christiana Mall**

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<td>Newark - Bus Rts: 5, 15, 33, 34, 39, 40, 41, 54, 55, 62, 63, 301, 305</td>
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**DE 273 & DE 7**

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<td>Newark - Bus Rts: 23, 40, 54</td>
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**Peoples Plaza**

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**Tybouts Corner**

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**Wrangle Hill**

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**Odessa Park & Ride**

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<tr>
<td>DE 1 &amp; DE 299</td>
<td>Middletown - Bus Rts: 43, 45, 301</td>
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**New Boyd’s Corner**

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<tr>
<td>DE 1 &amp; Pole Bridge Rd.</td>
<td>Odessa - Bus Rts: 45, 301</td>
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**Bethesda United Methodist Church**

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<tr>
<td>116 East Main St.</td>
<td>Middletown - Bus Rts: 43 (Board on Main St. at Catherine St.)</td>
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**Smyrna Rest Stop**

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<tr>
<td>Between US 13 &amp; DE 1</td>
<td>Smyrna - Bus Rts: 301, 305</td>
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**KENT COUNTY**

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<tr>
<th>Location</th>
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<tr>
<td>Scarborough Road</td>
<td>Dover - Bus Rts: 112, 301, 305</td>
</tr>
<tr>
<td>Delaware Agricultural Museum</td>
<td>886 North DuPont Hwy.</td>
</tr>
<tr>
<td>Water Street Transfer Center</td>
<td>Dover - Bus Rts: 109, 112</td>
</tr>
<tr>
<td>St. Andrew’s Lutheran Church</td>
<td>425 North DuPont Hwy.</td>
</tr>
<tr>
<td>Water Street Transfer Center</td>
<td>Dover - Bus Rts: 109, 112, 301, 303</td>
</tr>
<tr>
<td>- Paid Parking</td>
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</tr>
<tr>
<td>Faith Community Church</td>
<td>2240 South DuPont Hwy.</td>
</tr>
<tr>
<td></td>
<td>Dover - Bus Rts: 104, 303</td>
</tr>
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**Bike Lockers**

**For information:**

Call 1-800-652-DART
Or visit DartFirstState.com
Park & Rides (continued)

SUSSEX COUNTY

Del Tech Georgetown  
Jack F. Owens Campus  
Georgetown - Bus Rts: 206, 212, 303

Rehoboth Beach Park & Ride  
DE 1 & Shuttle Rd.  
Rehoboth - Bus Rts: 201, 203-208, 305  
Paid Parking (open May to September)

Park & Pools – Lots are available to park your car and meet a carpool or vanpool. Call RideShare Delaware for carpool matching services at 1-888-RideMatch.

NEW CASTLE COUNTY

Lantana Square  
DE 7 & Valley Rd., Hockessin

Delcastle Recreation Center  
McKannans Church Rd.

Brandywine Springs Park  
Faulkland Rd. & DE 41

Greenbank Park  
Greenbank Rd.

I-95 Service Plaza  
Newark

Boyd’s Corner  
DE 896 & US 13, Odessa

South Odessa  
US 13 at Wallace Rd.

Pine Tree Corner  
US 13 & Rd. 25, Townsend

KENT COUNTY

Shore Stop  
US 13 & Road 31, Canterbury

Harrington Moose Lodge  
US 13, Harrington

Milford Bowling Lanes  
809 North DuPont Hwy.  
Milford - Bus Rt: 303

SUSSEX COUNTY

Seaford Church of Christ  
US 13 & Rd. 532, Seaford

First Baptist Church  
601 N. DuPont Hwy., Georgetown

Sussex (continued)

St. Jude’s Catholic Church  
DE 1 (north of Five Points), Lewes

Lutheran Church of Our Savior  
DE 1 & Bay Vista Rd., Rehoboth

8
Most of these park and ride facilities are free to use, except for Rehoboth Beach park and ride which charges 8 dollars (including up to four free daily bus passes) from May to September, and Frawley Stadium and Riverfront park and ride both of whom charge $2.4 for daily basis. The latter two are not even publicly listed on DART’s website partly because they are very close to central Wilmington.

2.2 Park and Ride Classifications

2.2.1 By Distance to Destination

Researchers often classify park and ride lots by their distances to destinations, either central business districts or some employment centers. Those close to CBDs are called peripheral park and rides, while sub-urban facilities are called remote park and rides [12, 26].

[13] claimed that peripheral park and rides lie within a range of less than 3 miles or 4.8 kilometer. However, there’s no consensus about where to draw the line between these two types, because sometimes even park and rides located in sub-urban areas may operate more like peripheral facilities if the lot is placed close to a large suburban employment center. Moreover, practically park and ride facilities usually show a mixture of these two types.

Nevertheless, it’s beneficial to separate these two types because peripheral and remote park and rides differ in several ways:

First, they may have different customer types. Since peripheral ones are closer to destination, transit service only contributes a minor part in the trip and automobile will be the major piece. Therefore, users of peripheral park and ride facilities may care more about conditions in destination area, such as parking lot availability in CBD areas, parking fees, traffic congestions etc. On the other hand, for remote park and ride users, majority of their trip will rely on the public transit services. As a result, they may care more about scheduling, frequencies, and cost of transit service than the about the driving part.
Second, these two types of park and ride facilities tend to have different service ranges or catchment areas. [29] confirmed this phenomenon in both North Central Texas Council of Governments project and Puget Sound region.

### 2.2.2 By Transit Modes

Park and ride facilities can be used to connect different public transit systems to automobiles. Intuitively, they can be categorized by transit systems they connect to. Trains and buses are the two prevalent public transit services in Delaware so we’ll focus only on them. The most notable difference between train-based and bus-based park and ride facilities in Delaware is their utilization rates. See Figure 2.1 for different utilization patterns of train-based and bus-based park and ride lots:

![Boxplot of utilization by transit type](image)

**Figure 2.1: Utilization Patterns of Park and Ride by Transit Types**

Note that these two transit modes may not be mutually exclusive. Train-based park and ride facilities also serve bus lines passing by. Moreover, since many commuters may not drive to train stations and may choose to take a bus there instead, transportation
offices tend to route bus lines through train stations or even make train stations transit hubs.

For example, Newark train station has four bus lines (with line 39 board on South College Avenue) associated with it, while Fairplay station has five lines.

In our study, we assumed that people use train-based park and ride lots mostly for taking trains instead of taking buses.

2.2.3 By Ownership

Park and ride facilities can be built from scratch. This approach can be very expensive. For instance, according to DelDOT, an expansion of the park and ride located at the intersection of SR 299 and SR 1 from 102 parking spaces to 209 spaces cost about 1.4 million dollars. Moreover, There’s often little direct financial return from these projects because these park and ride facilities are usually free to use in order to encourage drivers to adopt this approach.

Although costly, dedicated park and ride facilities usually have higher capacity and are better equipped.

On the other hand, park and ride facilities can be established by utilizing existing parking lots at shopping centers and churches. The advantage of shared park and ride is less construction cost and fast deployment. But people may be less aware of their existence.

See Figure 2.2 a comparison between self-owned and shared park and ride lots in Delaware.
Figure 2.2: Capacities of Park and Ride Facilities by Ownership
Chapter 3
TRAIN-BASED PARK AND RIDE SYSTEM

3.1 Introduction

Delaware has two passenger railway lines: the Northeast Corridor (NEC) primarily owned and operated by Amtrak, and Southeastern Pennsylvania Transportation Authority’s (SEPTA) Wilmington/Newark Line. These two lines share the same railroads. SEPTA stops at all four railway stations: Claymont, Wilmington, Churchman’s Crossing, and Newark. Amtrak stops only at Wilmington and Newark.

Three of these four train stations have park and ride facilities: Newark Train station, Fairplay Station at Churchmans Crossing, and Claymont Train Station. Their locations are shown in Figure 3.1.

Train-based park and ride facilities can all be viewed as remote park and ride because they are all located far away from central business districts. As a result, public transit service will be a major part in commuter’s trip.
Figure 3.1: Train-based Park and Ride Facilities in Delaware

3.2 Model

There are basically two effects determining the distribution of the park and ride demand: the gravity effect and the modal effect. The gravity effect is named to show the distribution of commuters in the vicinity of a city or a CBD area, that is, the closer the area is to the city center, the more the demand will be. On the other side, the modal effect is used to describe the influence of park and ride facilities on the demand. Our hypothesis is similar to the foregoing statement that the closer the customer is to the park and ride lot, the more likely he or she will use the facility.

3.2.1 Modal Choice

Multinomial logistic regression is the prevalent model when dealing with modal choices. The dependent variables are usually different transportation alternatives which are categorical valued. In our study, we will only consider two different travel modes:
driving directly from residency A to destination B, or driving from A to park and ride P, and then take public transit service to destination P.

![Figure 3.2: Choice of Different Traffic Modes](image)

Suppose each person $i$ attaches different levels of utilities $U_{ij}$ to travel mode $j$. $U_{ij}$ is then linearly dependent upon some initial fixed utility level $U_i$, travel time $T_{ij}$, travel cost $C_{ij}$, mode related fixed effects $\beta_{Fj}$ such as concerns about safety and environment, and some person-specific random variable $\varepsilon_{ij}$ in the following way:

$$U_{ij} = U_i - \beta_{Fj} - \beta_T T_{ij} - \beta_C C_{ij} - \varepsilon_{ij}$$  \hspace{1cm} (3.1)

These utility levels cannot be directly observed, but their relationship can be revealed when people make their choices. Specifically, person $i$ will choose mode 1 when $U_{i1} > U_{i2}$, or $\Delta U = U_{i1} - U_{i2} = -[\beta_F + \beta_T (T_{i1} - T_{i2}) + \beta_C (C_{i1} - C_{i2}) + \varepsilon_i] > 0$ where $\beta_F = \beta_{F1} - \beta_{F2}$, $\varepsilon_i = \varepsilon_{i1} - \varepsilon_{i2}$.

If $\varepsilon_i$ follows a logistic distribution, which is very similar to the normal distribution but has heavier tails, then the probability of person $i$ choosing mode 1 is

$$P_{i1} = \frac{e^{U_{i1}}}{e^{U_{i1}} + e^{U_{i2}}} = \frac{1}{1 + e^{U_{i2} - U_{i1}}}$$  \hspace{1cm} (3.2)
3.2.2 Gravity Effect

If we know choices of all individuals, we can directly use Equation 3.2 to model people’s behavior. Alternatively, if we assume commuters to Philadelphia are evenly distributed within the state, we can also apply this model to demand aggregated at any level.

However, commuters’ residences are not evenly distributed, they have a tendency to live closer to their working area. This violates our assumption of even distribution. Furthermore, we don’t have individual-level survey. So we need to integrate this residency distribution into our model as well. One natural choice is spacial gravity model. Gravity model has been used extensively in transportation studies as well as in other disciplines.

There are many forms of gravity models and one of the most commonly used is

\[ T_{AB} = \kappa \frac{\Omega_A \Omega_B}{D_{AB}^\beta} \] (3.3)

where \( T_{AB} \) is the resulting number of trips between \( A \) and \( B \), \( \Omega_A \) and \( \Omega_B \) are the population of \( A \) and \( B \), respectively. \( D_{AB} \) is the distance between \( A \) and \( B \), \( \kappa \) and \( \beta \) are parameters.

Since in our study all commuters share the same destination \( B \) (i.e., Philadelphia), we can let \( k = \kappa P_B \) and simplify the model as

\[ T_{AB} = k \frac{P_A}{D_{AB}^\beta} \] (3.4)

3.2.3 Final Model

Combining Gravity model and Modal Choice model, we can get our final model for park and ride demand distributions. \( N_{iB,1} \), the number of commuters from district \( i \) who choose to use park-and-ride and take transit to district \( B \), is given by
\[ N_{iB,1} = T_{iB} P_1 \]
\[ = k \Omega_i \frac{1}{D_{iB}^\beta \left( 1 + e^{U_2 - U_i} \right)} \]
\[ = \frac{k \Omega_i}{D_{iB}^\beta (1 + e^{-[\beta_F + \beta_T \Delta T + \beta_C \Delta C + \epsilon_i]})} \]  \hspace{1cm} (3.5)

\( k, \beta, \beta_F, \beta_T, \) and \( \beta_C \) are parameters that need to be calibrated.

3.3 Data

3.3.1 Demand and Aggregation Level

Train-based park and ride demand survey was conducted between 9AM and 12AM on August 30 2010, Monday. See Figure 3.3 for pictures taken at each station.

![Newark Station](image1)

![Fairplay Station](image2)

![Claymont Station](image3)

![Claymont Overflow](image4)

Figure 3.3: Pictures of Train-based Park and Rides
For each park and ride, we record license plate information of all cars parking in the facility. Since we don’t have access to license registration data for out-of-state cars, we only use Delaware data in our study. As shown in Figure 2.1, all train-based park and ride facilities have high utilization rates.

These license plates are then geo-located to ZIP+4 code level with the help of Delaware Devison of Motor Vehicles. Of 668 vehicles parking at these train-based park and ride stations, 38 or 5.69% cannot be geographically located.

We don’t have data at individual level, so we need to aggregate our demand at some demographic or geographic region. ZIP+4 is not a good candidate because the total number of ZIP+4 areas is too big (61233) relative to our demand. This will generate too many zeros in our dependent variable and will cause problems in following regressions.

In our study, we use 5-digit ZIP Code area, or more precisely, ZIP Code Tabulation Areas (ZCTAs) defined by US Census Bureau, as our aggregation level. According to US Census Bureau, ZCTAs are generalized areal representations of USPS ZIP Code service areas. In most cases the ZCTA code is the same as the ZIP Code for an area, but not all ZIP Codes have ZCTAs because PO Boxes are excluded in ZCTAs. In our report, we use ZCTAs and ZIP Code areas interchangeably. Discussions about other possible levels are shown in Section 4.5.1 on page 47.

Demand of each park and ride facility aggregated at 5-digit ZIP Code level is shown below in Figure 3.4. Note that Claymont Station and Claymont Overflow are treated as one station. Shapes of ZIP Code areas are obtained from US Census TIGER/Line Products.
Figure 3.4: Train-based Park and Ride Demand by Zip Code
3.3.2 Demographic Data


Housing and population information are used in our study where total housing units and occupied housing units are obtained from Summary File 1, while total population age group are obtained from Summary File 2, 2010 census.

The difference between Summary File 1 and Summary File 2 is that the latter has a population threshold of 100: data are available only for the population groups with a population of 100 or more of that specific group within a particular geographic area.

In Delaware, 10 Zip Code areas out of a total of 67 are excluded from Summary File 2 for this reason, and thus do not have population information. These areas are either University of Delaware or residency areas for retired or disabled workers: 19710, 19716, 19717, 19732, 19735, 19736, 19902, 19936, 19955, 21912.

Total population for each ZIP Code area are used in our model calibration.

3.3.3 Distances

There are several distances involved in this study: distances between residential areas and central Philadelphia for driving mode, distances between residential areas and park and ride facilities, and distances between park and rides and central Philadelphia for park and ride mode.

Both residency regions and working places are areas instead of single points, so average distances are calculated using center points of each region. For Zip Code areas, geographic centers are used. Center of Philadelphia is assigned to Philadelphia City Hall at (39 57.140’, -75 9.819’), or (39.95233, -75.16365).

Great-circle distances are then calculated by Haversine Formula in which radius of the Earth is set as 6378.145 kilometers, or 3963.2 miles. Finally, driving distances are obtained by multiplying the great-circle distances by a factor of 1.2.
3.3.4 Travel Time

Total travel time is very hard and tedious to collect, many literatures include times of walking to the car, driving to destination area, finding parking space, and then walking to work place, etc. for driving mode. For park and ride mode, they consider times of walking to the car, driving to park and ride, parking and waiting for public transit service, time on the train, and then walking to work place after arriving at Philadelphia train station.

In our model, only the difference of travel time between two modes matters. Since a major portion of time for both modes are spent on driving cars or taking trains, we approximate the difference of total travel times of two modes by the difference between times spend on the road.

Driving time is obtained from dividing distance by driving speed. In our study, we set local driving speed at 30 miles per hour, and freeway speed at 50 miles per hour. In general, people tend to drive over the speed limit at both local roads and highways. However, since our targets are mainly commuters, we should use peek hour driving speed, which is lower than average driving speed. Following literatures, each trip is divided to 30 percent of local road and 70 percent of highway.

Time on public transit systems are directly collected from published weekday schedules (see Table 3.1):

- Newark Train Station to Philadelphia (30th Street Station): 1 hour and 12 minutes.
- Churchmans Crossing: 1 hour and 5 minutes.
- Claymont Train Station: 44 minutes.

In general, public transit is more time consuming than automobiles if we don’t take into account the time for finding parking spots in central Philadelphia.
Table 3.1: Weekday Schedules of Wilmington/Newark Line

3.3.5 Travel Cost

Travel costs consist of fuel expenses, transit fares, and parking fees. Fuel expenses can be computed from driving distances, fuel efficiencies and gas prices, while transit fares are generally public.

Fuel Efficiency: 23.3 miles per gallon (MPG)

According to Bureau of Transportation Statistics, United States Department of Transportation, this is the average fuel efficiency of U.S. light duty vehicle with short wheel base, which, based on categorization developed by Federal Highway Administration (FHWA), includes passenger cars, light trucks, vans and sport utility vehicles with a wheelbase (WB) equal to or less than 121 inches.

Gas Price: 2.734 dollars per gallon.

This is an average of all grades reformulated retail gasoline prices in Central Atlantic area on August 30 2010, the same day of our survey, released by U.S. Energy Information Administration (EIA).
According to its definitions, sources and explanatory notes, this is a weighted average of all three grades of Reformulated Gasoline (regular, mid-grade, and premium) by their sales volume, and represents the self-serve price except in areas having only full-serve.

Reformulated Gasoline (RFG), as mandated by Congress in the 1990 Clean Air Act amendments, is a specially blended gasoline to reduce smog-forming and toxic pollutants required in cities with high smog levels. United States Environmental Protection Agency shows that both New Castle County and Kent County have implemented Clean Air Act, while Sussex County and Sussex non-attainment area voluntarily “opt-in” to this program. Thus reformulated retail gasoline prices are used in this study.

Since gas price is never a universal, fixed or static number and varies over time, quality level and across different stations, cities, as well as counties, for city-level. U.S. Department of Energy website has a list of websites that has gas prices for some selected cities in Delaware.

Transit Fare: $4.34 per trip.

SEPTA has a variety of fare options as shown in Table 3.2. Since park and ride users are most commuters, it should be natural to assume that they will buy plans in advance instead of purchasing tickets on board. All three park and ride facilities are in zone 4, so we would use the Monthly TrailPass of $191.00. Divided by 22 working days per month, we can get our transit fare as $8.68 per round-trip or $4.34 per trip.

Parking Cost at Philadelphia

According to USA Today, The average monthly parking cost in central district area is $304 per month, or $13.82 per day.
### REGIONAL RAIL FARE SUMMARY

<table>
<thead>
<tr>
<th>ZONE</th>
<th>Weekday</th>
<th>Evening &amp; Weekend</th>
<th>10 TRIP TICKETS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(A)</td>
<td>(B)</td>
<td>(A)</td>
</tr>
<tr>
<td>CCP/1</td>
<td>$4.75</td>
<td>$6.00</td>
<td>$3.75</td>
</tr>
<tr>
<td>2</td>
<td>$4.75</td>
<td>$6.00</td>
<td>$3.75</td>
</tr>
<tr>
<td>3</td>
<td>$5.75</td>
<td>$7.00</td>
<td>$5.00</td>
</tr>
<tr>
<td>4</td>
<td>$6.50</td>
<td>$8.00</td>
<td>$5.00</td>
</tr>
<tr>
<td>NJ</td>
<td>$9.00</td>
<td>$10.00</td>
<td>$9.00</td>
</tr>
</tbody>
</table>

**WEEKDAY**
Valid Monday-Friday, 4:00 a.m. – 7:00 p.m.
(Train Arriving/Departing 30th St, Suburban, Market East Stations)

**EVENING/WEEKEND**
Valid Monday-Friday, 7:00 p.m. – last train
(Train Arriving/Departing 30th St, Suburban, Market East Stations)
All day Saturday, Sunday, Major Holidays

(A) Advanced Sales: Purchase at Ticket Office or online at shop.septa.org
(B) Cash Fare: Purchase from Train Conductor All fares subject to change

### TABLE 3.2: REGIONAL RAIL FARE STRUCTURE

<table>
<thead>
<tr>
<th>ZONE</th>
<th>Weekly TrailPass</th>
<th>Monthly TrailPass</th>
<th>Weekly Cross County</th>
<th>Monthly Cross County</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$27.25</td>
<td>$101.00</td>
<td>$29.00</td>
<td>$109.00</td>
</tr>
<tr>
<td>2</td>
<td>$36.50</td>
<td>$135.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>$44.00</td>
<td>$163.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anywhere</td>
<td>$53.00</td>
<td>$191.00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3.4 Results

3.4.1 Calibration Results

Parameters are calibrated using non-linear least squares method. Since non-linear problem usually has no closed-form solutions, iterative numeric solutions are calculated using R package DEoptim.

Lower bound, upper bound, and estimated value for each parameters are shown in Table 3.3:
Table 3.3: Bounds and Values of Parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>k</th>
<th>β</th>
<th>βF</th>
<th>βT</th>
<th>βC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Bound</td>
<td>0</td>
<td>0</td>
<td>-10000</td>
<td>-10000</td>
<td>-10000</td>
</tr>
<tr>
<td>Upper Bound</td>
<td>1000</td>
<td>5</td>
<td>10000</td>
<td>10000</td>
<td>10000</td>
</tr>
<tr>
<td>Value</td>
<td>15.76</td>
<td>3.01</td>
<td>-149.18</td>
<td>-724.63</td>
<td>-70.82</td>
</tr>
</tbody>
</table>

So our train-based park and ride demand model is:

\[
i_{B,1} = \frac{15.76\Omega_i}{D_{iB}^{3.01} \left(1 + e^{149.18 + 724.63\Delta T + 70.82\Delta C}\right)}
\]  

(3.6)

where \(N_{iB}\) is the demand generated from district \(i\) to location \(B\) which is Philadelphia here, \(\Omega_i\) is population in district \(i\), \(D_{iB}\) and \(\Delta T, \Delta C\) can be computed given geo-location of \(i\).

Note that although we use aggregated data for calibration, this model is a continuous model thus can be applied at any location, not just center of ZIP Code areas.

3.4.2 In-Sample Predictions

Using Equation 3.6, we can generate in-sample predictions for each park and ride facility. Comparisons of real demand and in-sample predictions are shown below from Figure 3.5 to Figure 3.7.

Figure 3.5: Real and Predicted Demand for Newark Station
3.4.3 Demand Forecast

Using Equation 3.6, we can also predict incremental demand generated by any new establishments. Only geographic location of the new development project as well as the predicted number of occupants are needed.

Steps to get demand forecasts are:

Step 1 Calculate distance between target development and park ride facility, as well as distance between target development and Philadelphia $D_{i,Philly}$.

Step 2 Compute travel time for park and ride mode $T_1$ and for driving mode $T_2$ using distances calculated at previous step, and get travel time difference $\Delta T$.

Step 3 Compute travel cost for park and ride mode $C_1$ and for driving mode $C_2$ using distances calculated at Step 1, and get travel time difference $\Delta C$. 

26
Step 4 Now we have \( P_i, D_{i,Philly}, \Delta T, \) and \( \Delta C \), we can then plug their values into Equation 3.6 and get demand forecast. Note that \( P_i \) should be total population at development \( i \), other capacity data should be transformed to population first.
Chapter 4

BUS-BASED PARK AND RIDE SYSTEM

4.1 Introduction

Bus system is the primary public transportation system in Delaware, and is run by DART First State. Most (44) bus routes are operated in and around Wilmington and Newark in New Castle County. Another large hub is Dover in Kent County which has 14 bus routes. Georgetown in Sussex County has two bus routes. In addition to these bus routes, DART also operates two inter-county lines (route 301 and route 303), eight seasonal resort services, and one bus routes - “the Bus” that leads into Elkton, Maryland.

These bus lines can be categorized into three groups: Community Circulator, Core, and Express. Their lengths are compared in the following Figure 4.1. The two outliers in group “Express” are the two inter-county lines.

36 bus-based park and ride facilities serve the bus system. Similar to the bus system, most of them are in New Castle County. There are also many park and rides along with the inter-county bus routes connecting Wilmington, Newark, Middle Town, Smyrna and Dover. These park and rides, along with Christiana Mall park & ride, DE 896 & DE 4 park & ride close to University of Delaware, and one at People’s Plaza, are the nine facilities we will investigate in this project. (See Figure 4.3 for all these park and ride facilities and bus routes they serve.)

Note that these facilities are not randomly chosen. Compared to those non-chosen park and rides, these nine facilities are all dedicated only for park-and-ride purpose and have larger capacities as shown in Figure 4.2. We can also see from Figure 4.3 that most of these park and ride facilities being analyzed are remote park and ride.
Figure 4.1: Bus Line Lengths by Type

Figure 4.2: Capacities for Selected and Non-Selected Park and Rides
Figure 4.3: Park and Ride Selection
Unlike train-based park and ride parking lots which see high utilization rate, bus-based park and ride lots usually present very low usage in Delaware as shown below.

Table 4.1: Usage of Bus-based Park & Ride Facilities in Delaware

<table>
<thead>
<tr>
<th>Park &amp; Ride</th>
<th>DE</th>
<th>PA</th>
<th>MD</th>
<th>NJ</th>
<th>Other</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rehoboth Beach Park &amp; Ride</td>
<td>133</td>
<td>20</td>
<td>15</td>
<td>3</td>
<td>18</td>
<td>189</td>
</tr>
<tr>
<td>* Christiana Mall</td>
<td>97</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>101</td>
</tr>
<tr>
<td>* DE 896 &amp; DE 4</td>
<td>65</td>
<td>12</td>
<td>20</td>
<td>1</td>
<td>1</td>
<td>98</td>
</tr>
<tr>
<td>* Odessa Park &amp; Ride</td>
<td>50</td>
<td>3</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>60</td>
</tr>
<tr>
<td>* Smyrna Rest Stop</td>
<td>58</td>
<td>1</td>
<td></td>
<td>1</td>
<td>1</td>
<td>60</td>
</tr>
<tr>
<td>* Scarborough Road</td>
<td>52</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td>54</td>
</tr>
<tr>
<td>* Boyds Corner</td>
<td>47</td>
<td>1</td>
<td>2</td>
<td></td>
<td></td>
<td>50</td>
</tr>
<tr>
<td>North Baptist Church</td>
<td>28</td>
<td>8</td>
<td>1</td>
<td>1</td>
<td></td>
<td>38</td>
</tr>
<tr>
<td>DE 273 &amp; DE 7</td>
<td>25</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>36</td>
</tr>
<tr>
<td>Prices Corner</td>
<td>30</td>
<td>1</td>
<td></td>
<td></td>
<td>2</td>
<td>33</td>
</tr>
<tr>
<td>RCCSD C DE 52 &amp; DE 100 (DuPont Rd.)</td>
<td>23</td>
<td>9</td>
<td></td>
<td>1</td>
<td></td>
<td>33</td>
</tr>
<tr>
<td>Concord Presbyterian Church</td>
<td>30</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td>32</td>
</tr>
<tr>
<td>Faith Community Church</td>
<td>26</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td>30</td>
</tr>
<tr>
<td>* Peoples Plaza</td>
<td>13</td>
<td>5</td>
<td></td>
<td></td>
<td>1</td>
<td>18</td>
</tr>
<tr>
<td>* Tybout's Corner</td>
<td>16</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>17</td>
</tr>
<tr>
<td>Faith Presbyterian Church</td>
<td>15</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td>17</td>
</tr>
<tr>
<td>Aldersgate United Methodist Church</td>
<td>16</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>17</td>
</tr>
<tr>
<td>Hockessin Memorial Hall</td>
<td>9</td>
<td>6</td>
<td></td>
<td></td>
<td>1</td>
<td>16</td>
</tr>
<tr>
<td>* Wragge Hill</td>
<td>11</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td>13</td>
</tr>
<tr>
<td>Faith Baptist Church</td>
<td>10</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>11</td>
</tr>
<tr>
<td>Dover Transit Center</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>Lutheran Church of the Good Shepherd</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>Scottfield (Brookside)</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>Naamans &amp; Carpenter Roads</td>
<td>4</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Brandywine Town Center</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Lower Brandywine Presbyterian Church</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Trinity Presbyterian Church</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td><strong>Grand Total</strong></td>
<td>788</td>
<td>80</td>
<td>54</td>
<td>10</td>
<td>27</td>
<td>959</td>
</tr>
</tbody>
</table>

* Park & ride facilities being analyzed in this study.

4.2 Model

One critical assumption about our train-based park and ride model is that majority of the commuters go to a common destination – Philadelphia. This assumption
is no longer valid for bus-based park and ride systems because each park and ride facility now serve several bus lines and each line then will have multiple destinations.

As a result, it’s very hard for us to use the same Multinomial Logit model for bus-based park and ride systems. Instead, we’ll use a variant of multivariate regression model – Tobit model. Similar regression models have widely been used in other metropolitan regions in the United States, such as Albany, NY [13] and Seattle, WA [23].

4.2.1 Multiple Linear Regression

The underlying equation of multiple linear regression is:

$$Y_{ij} = \alpha_1 D_i + \alpha_2 D_j + \beta_1 X_i + \beta_2 X_j + \beta_3 X_{ij} + \varepsilon_{ij}$$  \hspace{1cm} (4.1)

where $Y_{ij}$ is the demand from residential area $i$ to use park and ride facility $j$, $D_i$ are dummy variables for residential area $i$, $D_j$ are dummy variables for park and ride $j$. $X_i$ are characteristics of residential areas, such as demographic data explained before; $X_j$ are attributes of park and ride facilities and $X_{ij}$ are variables that vary with both residential areas and park and ride facilities. $\alpha_1, \alpha_2, \beta_1, \beta_2, \beta_3$ are coefficients to be estimated, and $\varepsilon_{ij}$ is the error term. Notice that $Y$, $D$ and $X$ are all matrices while all coefficients $\alpha$ and $\beta$ can be vectors.

4.2.2 Tobit Regression

One problem of multiple linear regression is that its dependent variable can go from negative infinity to positive infinity while the true demand is always a non-negative real number.

Tobit model is a widely used statistical model proposed by Tobin [30] to describe this relationship between a non-negative regressand and regressors. It supposes that there exists an unobservable variable (such as utility level) $y_i^*$ which depends upon values of regressors $X_i$. The real regressand $y_i$ is defined to be equal to $y_i^*$ whenever the latent variable is above zero, and to be zero otherwise.
$y_i = \begin{cases} y_i^* & \text{if } y_i^* > 0 \\ 0 & \text{if } y_i^* \leq 0 \end{cases}$

If the true process is realized as above, ordinary least squares estimators obtained from multiple linear regression will be inconsistent. The estimates of slope coefficients will be biased downward while the intercept will be biased upward.

4.3 Data

Data for bus-related park and ride system can be categorized into three groups: one group varies across the park and ride facilities, for instance, number of bus lines passing this park and ride, number of competitors within given radius. Taken from Multiple Choices Logit Model, we can call it attributes of park and ride facilities. The second group varies across residential areas, such as demographic or income data. We call it characteristics of the residential areas. The last group includes aspects specific to the residential areas as well as to park and ride facilities. Examples are distances and actual demand.

4.3.1 Demand

Demand for each park and ride facility is surveyed during August 14 and August 16, 2013. Same procedures are followed in data collection: license plates of all Delaware vehicles are collected at each park and ride facility; these license plates are then geo-located to 5+4 digit ZIP code level with the help of Delaware DMV.

As shown in Table 4.1, the nine facilities we analyze have 471 vehicles, accounting for about half of all 959 users in the whole bus-based park and ride system. In terms of Delaware cars, these facilities have 409 cars, or 51.9% of all 788 Delaware cars in the system. During geo-location, we lost 55 observations because they cannot be located in ZIP Code areas.

Similar to train-based park and ride system, these observations have to be aggregated at some level for analysis. We still use 5-digit ZIP Code for aggregation.
Other possible aggregation are discussed at subsection 4.5.1. Distributions of vehicles for each park and ride facility can be seen from Figure 4.4a at page 38 to Figure 4.12a at page 46.

From the figure, we can see apparently that contrary to normal treatment of catchment area in the literature, there's no clear cut-off radius for the park and ride catchment but a gradual decay of demand with the increase of distance between residence areas and the corresponding park and ride facility.

4.3.2 Attributes of Park and Ride Facilities

Park and ride facilities differ on many things: lot sizes, accessibilities, maintenance and service levels, public safeties etc. Lot sizes are excluded from our regression because it should be viewed more likely as output variable rather than input variable of demand. In other words, planners would take into account expected demand when designing park and ride facilities. Since none of bus-based park and ride facilities are close to full utilization, it should be safe to do this. Furthermore, we'll also exclude all subjective evaluations such as accessibilities, service levels or safety issues in this project.

We are more interested in attributes of park and ride facilities that are related to the bus system: type and number of bus lines they serve, how frequently these bus lines are available, how many stops these bus lines have. We should also take into consideration competitions each park and ride faces.

Note that total number of bus lines passing a park and ride and total number of bus stops reachable from this park and ride may be highly colinear. The same is true for total frequencies of all buses serving that park and ride.

All bus line information are obtained from DART First State website. More specifically, number of bus stops is obtained by adding both “in” and “out” of each bus line listed at DART Bus Stop Listing. Note that some of these stops may be skipped except being asked. Bus frequency information are from DART Routes and Schedules. Information about “The Bus” can be found at Cecil County, MD Website.
A summary of these information are showed below:

Table 4.2: Bus Information for Selected Park and Rides

<table>
<thead>
<tr>
<th>Park &amp; Ride</th>
<th>Bus Routes</th>
<th>Total Frequencies</th>
<th>Total Stops</th>
</tr>
</thead>
<tbody>
<tr>
<td>DE 896 &amp; DE 4</td>
<td>16, 33, 39, 55, 65</td>
<td>124</td>
<td>405</td>
</tr>
<tr>
<td>Christiana Mall</td>
<td>5, 15, 33, 34, 39, 40, 41, 54, 55, 62, 63, 301, 305</td>
<td>286</td>
<td>960</td>
</tr>
<tr>
<td>Peoples Plaza</td>
<td>40, 41, 42, 55, “The Bus”</td>
<td>70</td>
<td>283</td>
</tr>
<tr>
<td>Tybouts Corner</td>
<td>25</td>
<td>51</td>
<td>103</td>
</tr>
<tr>
<td>Wrangle Hill</td>
<td>25</td>
<td>51</td>
<td>103</td>
</tr>
<tr>
<td>Odessa Park &amp; Ride</td>
<td>43, 45, 301</td>
<td>78</td>
<td>119</td>
</tr>
<tr>
<td>New Boyd’s Corner</td>
<td>45, 301</td>
<td>37</td>
<td>93</td>
</tr>
<tr>
<td>Smyrna Rest Stop</td>
<td>301, 305</td>
<td>32</td>
<td>87</td>
</tr>
<tr>
<td>Scarborough Road</td>
<td>120, 301, 305</td>
<td>66</td>
<td>123</td>
</tr>
</tbody>
</table>

Number of competitiors in adjacent area is hard to define because there is no consensus on the size of adjacent area. Past literatures suggest different values but they are either too high or too low in our project. To generate moderate distribution, we set the radius of competition as the average distance of all park and rides to their closest counterparts: 3.8 kilometers or 2.36 miles.

4.3.3 Characteristics of Residential Areas

Demographic data are obtained from 2010 U.S. Census same as before in chapter 3.

The reference date of 2010 U.S. Census, as said before, is April 1, 2010, about three and a half years before our survey date.

4.3.4 Distances

Unlike train-based park and ride system, here we’ll only use distances between residential areas and park and ride facilities because commuters have no common destination here.

The same algorithm is used to calculate the great-circle distances.
4.4 Results

4.4.1 Calibration Results

Results of Tobit model is given below:

\[
\text{Tobit regression} \\
\begin{array}{l}
\text{Number of obs } = 522 \\
\text{LR chi2(6) } = 52.04 \\
\text{Prob > chi2 } = 0.0000 \\
\text{Log likelihood } = 666.73389 \\
\text{Pseudo R2 } = -0.0406
\end{array}
\]

| PerWork | Coef.  | Std. Err. | t     | P>|t|  | [95% Conf. Interval] |
|---------|--------|-----------|-------|------|----------------------|
| to64Pop10 | 2.51e-08 | 4.86e-09 | 5.17  | 0.000| 1.56e-08            | 3.47e-08            |
| Dis_2   | 0.0057425 | 0.0017838 | 3.22  | 0.001| 0.002238            | 0.009247            |
| Competitors | 0.0002014 | 0.000104  | 1.94  | 0.053| -2.96e-06           | 0.0004057           |
| BusSchedule | -3.72e-06 | 4.09e-06 | -0.91 | 0.363| -.0000118           | 4.31e-06            |
| BusStops | 2.05e-06  | 1.50e-06  | 1.37  | 0.171| -8.92e-07           | 5.00e-06            |
| NoOfBusRoutes | -0.000928 | 0.000761  | -1.22 | 0.223| -.0002424           | 0.000567            |
| _cons   | -0.008854 | 0.001376  | -6.44 | 0.000| -.0011557           | -.0006151           |

\[
\text{/sigma } = 0.0007787 \\
\text{.0000509} \\
\text{.0006787 } \\
\text{.0008787}
\]

Obs. summary: 383 left-censored observations at PerWork<=0
139 uncensored observations
0 right-censored observations

From the results we can see 383 out of 522 observations are left-censored at zero.

Major findings include:

1. Coefficient of competitors are positive, indicating that there are spill-over effects rather than competition effects among adjacent park and ride facilities, i.e., other park and ride facilities nearby will increase demand to the facility being analyzed.

2. Among the three proxies of bus line information, total number of bus stops is the best proxy variable. Its coefficient is positive as expected because bus line with more stops will attract more commuters to its park and ride facility.

For comparison, results of multiple linear regression over dataset aggregated at 5-digit ZIP code level are shown below:
<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>Number of obs = 522</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>627.612123</td>
<td>6</td>
<td>104.602021</td>
<td>F( 6, 515) = 22.52</td>
</tr>
<tr>
<td>Residual</td>
<td>2392.31891</td>
<td>515</td>
<td>4.64527944</td>
<td>Prob &gt; F = 0.0000</td>
</tr>
<tr>
<td>Total</td>
<td>3019.93103</td>
<td>521</td>
<td>5.79641273</td>
<td>R-squared = 0.2078</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Adj R-squared = 0.1986</td>
</tr>
</tbody>
</table>

| ActualUser | Coef.  | Std. Err. | t    | P>|t| | [95% Conf. Interval] |
|------------|--------|-----------|------|----|----------------------|
| to64Pop10  | .0000839 | .0000101  | 8.27 | 0.000 | .000064 - .0001038 |
| Dis_2      | 28.93562 | 4.486889  | 6.45 | 0.000 | 20.12076 - 37.75048 |
| Competitors| .2309359  | .2234465  | 1.03 | 0.302| -.2080429 - .6699147|
| BusSchedule| -.0010484 | .0083886  | -0.12| 0.901| -.0175285 - .0154318|
| BusStops   | .0004477  | .0031053  | 0.14 | 0.885| -.005653 - .0065483 |
| NoOfBusRoutes| .0364757 | .1520594  | 0.24 | 0.811| -.2622573 - .3352087|
| _cons      | -.5758461 | .2398005  | -2.40| 0.017| -1.046964 - .1047386|

It’s easy to find out that many coefficients lose their significance in linear regression, indicating that Tobit model should be better in this context.

After all, our final model for bus-based park and ride demand is:

\[ N_{ij} = \text{Max}(0, -8.85 \times 10^{-4} + 2.51 \times 10^{-8} \times \Omega_i + 5.74 \times 10^{-3} \times D_{ij}^{-2} + 2.01 \times 10^{-4} \times \text{Comp}_j - 3.72 \times 10^{-6} \times \text{Scle}_j + 2.05 \times 10^{-6} \times \text{Stop}_j - 9.28 \times 10^{-5} \times \text{Rout}_j) \] \hspace{1cm} (4.2)

where \( \Omega_i \) is population level at district \( i \), \( D_{ij} \) is the distance between district \( i \) and park-and-ride \( j \), \( \text{Comp}_j \) is number of competitors for park-and-ride \( j \), \( \text{Scle}_j, \text{Stop}_j, \text{Rout}_j \) are number of total frequencies, number of stops reachable, and number of bus routes for park-and-ride \( j \).

### 4.4.2 In-Sample Predictions

Using Equation 4.2, we can easily generate in-sample predictions for each park and ride facility. Comparisons of real demand and in-sample predictions are shown below from Figure 4.4 at page 38 to Figure 4.12 at page 46.
Figure 4.4: Real and Predicted Demand at Christiana Park and Ride
Figure 4.5: Real and Predicted Demand at DE896 & DE4 Park and Ride
Figure 4.6: Real and Predicted Demand at Odessa Park and Ride
Figure 4.7: Real and Predicted Demand at Smyrna Park and Ride
Figure 4.11: Real and Predicted Demand at Tybouts Park and Ride
4.5 Discussion

4.5.1 Aggregation Level

Through our project, we use 5-digit ZIP Code level as our aggregation level. In this section, we will look at other possible aggregation levels as well. Since we need demographic information especially population data for our regression, our aggregation level should be constrained to levels that have demographic information available.

Candidates of aggregation levels and their sizes are:

1. Zip Code: 67
2. Census Tract: 218
3. Census Block Group: 574
4. Census Block: 24170
5. ZIP+4 Code: 61233

As stated before, our dependent variable (total demand in Delaware) has only 668 observations for train-based park and ride, and 409 observations for bus-based system. So Census Block and ZIP+4 Code can be excluded because they would cause too many zeros in dependent variables.

Since our raw data from DMV is at ZIP+4 level, if we want to use Census Tract or Census Block Group as our aggregation level, we need to match ZIP+4 records with Census Tract. This matching is accomplished using TIGER/ZIP products bought from USPS. Demand in these multiple-tract ZIP+4 areas will be distributed evenly into relevant tracts. Of the 61233 ZIP+4 Code areas, 1188 are found to belong to 2 tracts, 38 belong to 3 tracts.

One candidate aggregation level is US census tract whose number is 218, about two and a half times larger than number of ZIP code areas. A good thing about census tract is that according to U.S. Census Bureau definition, census tracts are “designed to be relatively homogeneous units with respect to population characteristics, economic status, and living conditions, census tracts average about 4,000 inhabitants.”
However, of the 408 license plate records, 54 cannot be identified at ZIP Code level, 9 are dropped because they do not have “+4” codes. But one more severe problem is that 123 observations with ZIP+4 codes cannot be indentified in USPS TIGER/ZIP+4 database. The reason, according to USPS, is that ZIP+4 is designed to facilitate mail sorting and delivery, not to represent rigorously defined geographic regions. For example, some ZIP+4 may represent one side of a road plus a part of a building. Thus it’s hard to precisely geo-locate these area. Another important reason is that P.O. boxes do not have any geo-location information.

So in the end, we are left with 222 valid observations out of 408 license plate records for the nine park and ride facilities being analyzed. Among these 222 observations 5 need to be divided into 2 different census tracts. This loss is so huge that we cannot use this data to calibrate our model. The same is true or even worse for Census Block Group.

Although we cannot use Census Tract or Census Block Group as aggregation level, we can see from Figure 4.13 that the demand decay follows the same trend as predicted in our model.

4.5.2 Selection of Population Proxy

Different proxies can be used as alternatives of total population: 2010 U.S. Census provides other three candidates: total housing units, occupied housing units, and working age population (18 to 64).

These four variables have strong linear correlations as shown below in Figure 4.14 and different proxies have little impact on our findings. Among these four variables, total population has the largest explaining power.

4.5.3 Distance Decay Speed

We also test different distance decay speeds in bus-based park and ride system and find out that -2 would be the best decay speed as shown below in Figure 4.15.
Figure 4.13: Christiana Park and Ride Demand Aggregated by Census Tract
Note this decay speed is different from our parameter $k$ in train-based park and ride system where $k$ is the distance parameter for Philadelphia commuters distribution.
REFERENCES


## Glossary

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DelDOT</td>
<td>Delaware Department of Transportation</td>
</tr>
<tr>
<td>DTC</td>
<td>Delaware Transit Corporation</td>
</tr>
<tr>
<td>FHWA</td>
<td>Federal Highway Administration</td>
</tr>
<tr>
<td>RFG</td>
<td>Reformulated Gasoline</td>
</tr>
<tr>
<td>TIGER</td>
<td>Topologically Integrated Geographic Encoding and Referencing</td>
</tr>
<tr>
<td>ZCTA</td>
<td>ZIP Code Tabulation Areas</td>
</tr>
</tbody>
</table>