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THE STATISTICAL AND GEOGRAPHICAL ANALYSIS ON THE IMPACTS OF SOCIOECONOMIC CHARACTERISTICS ON BUS-STOP DAILY BOARDING IN RICHMOND CITY

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The Statistical and Geographical Analysis on the Impacts of Socioeconomic Characteristics on Bus-Stop Daily Boarding in Richmond City

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Urban and Regional Planning at Virginia Commonwealth University

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Abstract

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At present, Richmond, Virginia only has bus transit services provided by the Greater Richmond Transit Company (GRTC) and primarily concentrated within the boundary of Richmond City. GRTC is impacted by both supply-side and demand-side factors, notably socioeconomic characteristics of bus riders, bus ridership is unevenly distributed across different bus stops.

This thesis will conduct statistical and geographical analysis on the impacts of socioeconomic characteristics on bus-stop daily boarding in Richmond City. The statistical analysis includes both correlation analysis and regression analysis, assuming one dependent variable (bus-stop daily boarding) and fourteen independent variables (most of which describe socioeconomic characteristics of bus riders) at aggregated census

block group levels. The research concentrates on local bus routes and the block groups with local bus stops in Richmond. This empirical study aims to identify the significant factors impacting bus ridership and assess the bus service situation for affected block groups (under-served or over-served). The study outcomes, such as the number of bus lines as the most important factor impacting ridership, will have important implications for Richmond’s local transit planning and decision-making.

CHAPTER 1: INTRODUCTION

1.1 Existing Problems

The Greater Richmond Transit Company (GRTC) currently operates a hub-and-spoke bus transit system for the Richmond region. GRTC's local service area includes most portions of the Richmond City, significant parts of Henrico County, and limited areas of Chesterfield County. GRTC's express routes, which are not studied in this thesis due to its diffused locations and the nature of express service, serve to offer commuting choices rather than provide a comprehensive transit service.

The stop-level bus ridership of GRTC's local service is unevenly distributed in the Richmond region. Examining its cause motivates this study, which should have important planning and policy implications for GRTC and local community.

1.2 Research Objectives

This thesis has three objectives:

To develop and evaluate bus-stop level ridership models using GIS and statistical methods to identify the significant factors which impact public transit ridership.

To identify through the ridership modeling analysis, block groups are under-served or over-served by GRTC bus lines.

To provide important policy implications on GRTC's transportation decision-making and local transportation development.

1.3 Research Methods

This study is based on literature reviews and a rigorous data analysis on the transit ridership influenced by block group-level socioeconomic variables. Geographic information system (GIS) is used to show different transit ridership situations by bus stop service and regression analysis to examine and analyze factors which may significantly influence public transit ridership.

1.4 Research Scope

My research concentrates on local bus routes and the block groups which have local bus stops in Richmond City. GRTC's bus route structure is classified as a hub-and-spoke system, where service converges on a central downtown area and then spreads out into the surrounding neighborhoods. But according to the 2007 household survey in Comprehensive Operations Analysis conducted by GRTC (2008), 86 percent of fixed route service is provided to the downtown area, most local bus routes support downtown area, and only express routes provide direct service between downtown and suburbs. According to the GRTC Annual Ridership in calendar year 2010, more than 80 percent of the ridership was made by local bus routes. (Figure 1)

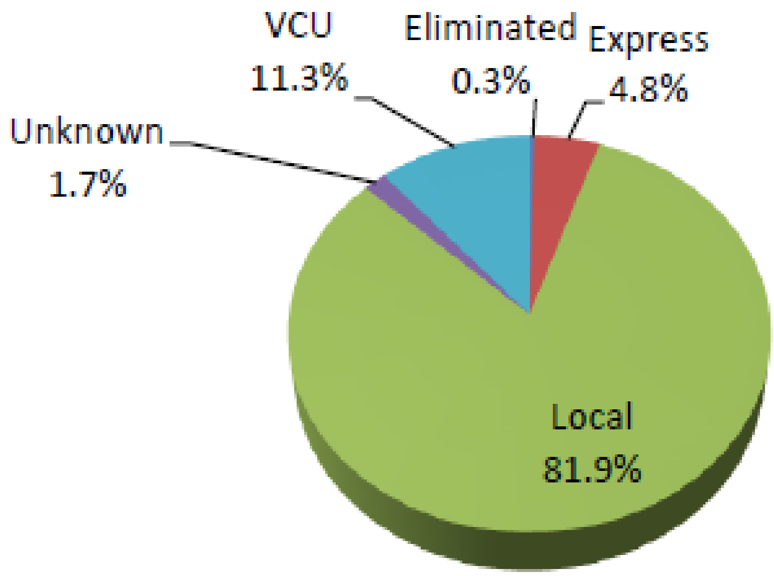


Figure 1: Percentage of Total Ridership by Route Category (Source: GRTC GFI DATA, 2010)

1.5 Research Contribution

Researching and understanding the important factors that influence public transit ridership and existing deficiencies are useful to support a sustainable transit system that reduces traffic congestion, provides mobility to the disadvantaged, enhances economic development, conserves energy and improve air quality. Assessing each affected block group's ridership supports that goal and offers information valuable for policies established by Richmond's transit and planning agencies.

1.6 Research Factors

Population (total population), population density (total persons/acre),employment density (employees/acre), income (median household income) car ownership (the number of vehicles in household), acres (the size of each block group), black ratio (black population/total population), female rate (total female population/ total population),households (total households), household density (households/acre), low-skilled jobs (total low-skilled employment), low educated people (educational attainment (under and not including high school)), unemployment rate (total unemployed/ total population), and the number of bus lines in each block group are my independent variables. The daily number of passengers boarding on a bus at any bus stop aggregated by block groups, is my dependent variable.

CHAPTER 2: LITERATURE REVIEW

2.1 The public transit situation and issues of the U.S and Richmond, VA

City public transit systems play a vital role in carrying large shares of personal travel in metropolitan areas around the world. But as shown in Figure 2, in most places, public transit has been losing market share to private vehicles. In the market share of metropolitan travel, public transit is losing customers to private vehicles in the U.S. "Nationally, only 2.1% of all trips were on public transit in 2001, compared to 85.8% by private vehicles, 9.9% by foot and bicycle, and 2.2% by other means" (U.S. Department of Transportation, 2001). Transit use is higher in the centers and downtowns of the bigger city and metropolitan areas. "In the U.S., New York City is the 800-pound transit gorilla – nearly 4 in 10 (38%) transit trips nationally in 2000 were made in the greater New York City area" (American Public Transportation Association, 2001).

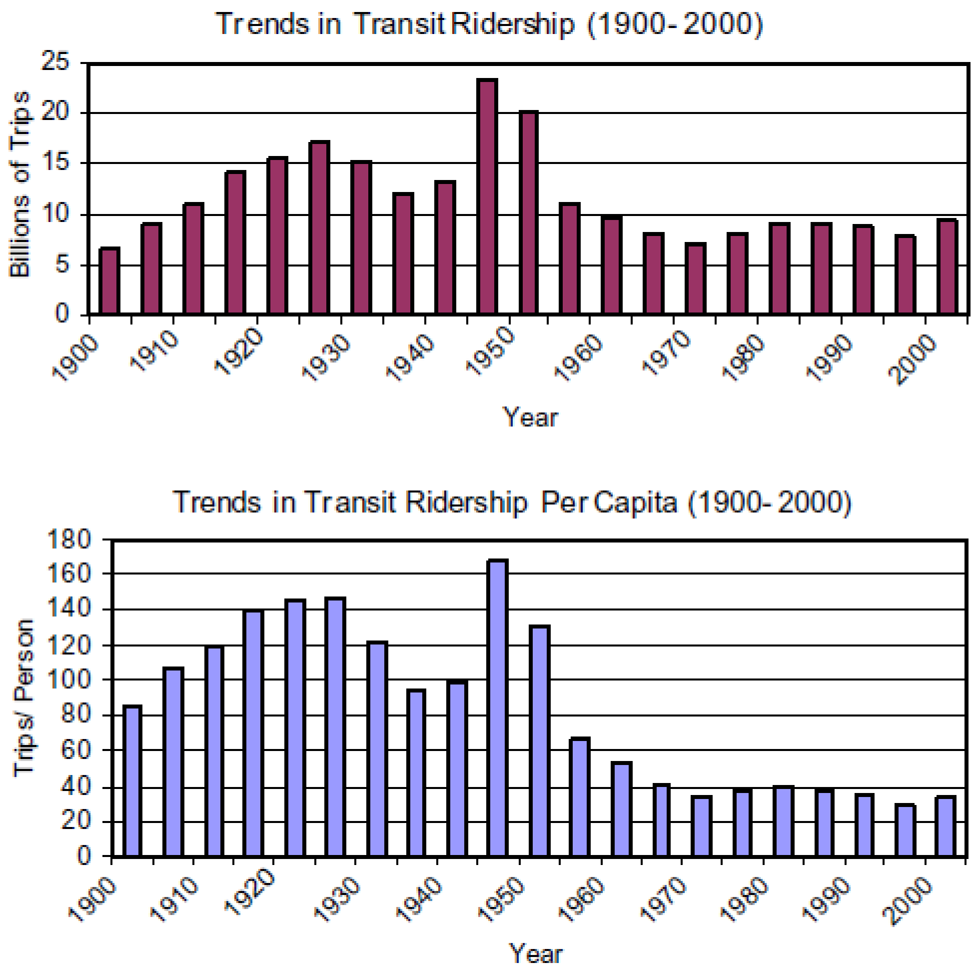


Figure 2: Annual transit ridership and annual ridership per capita in the US [Source: American Public Transportation Association (2001)]

As seen in Figure 3, in recent years, with the economy recovering and employment rate improving and higher gas prices, American transit use has gradually been rising. “From 1995 to 2009, public transportation ridership in the U.S. grew at a rate of 34 percent – twice as fast as the population growth rate and 10 percentage points faster than the growth rate of vehicle miles traveled on our road and highway system” (Amalgamated Transit Union, n.d.). According to a recent report released in 2012 by the American Public Transportation Association (APTA), “Americans took 10.4 billion trips on public transportation in 2011, the second highest annual ridership since 1957, and this was the sixth year in a row that more than 10 billion trips were taken on public transportation systems nationwide."

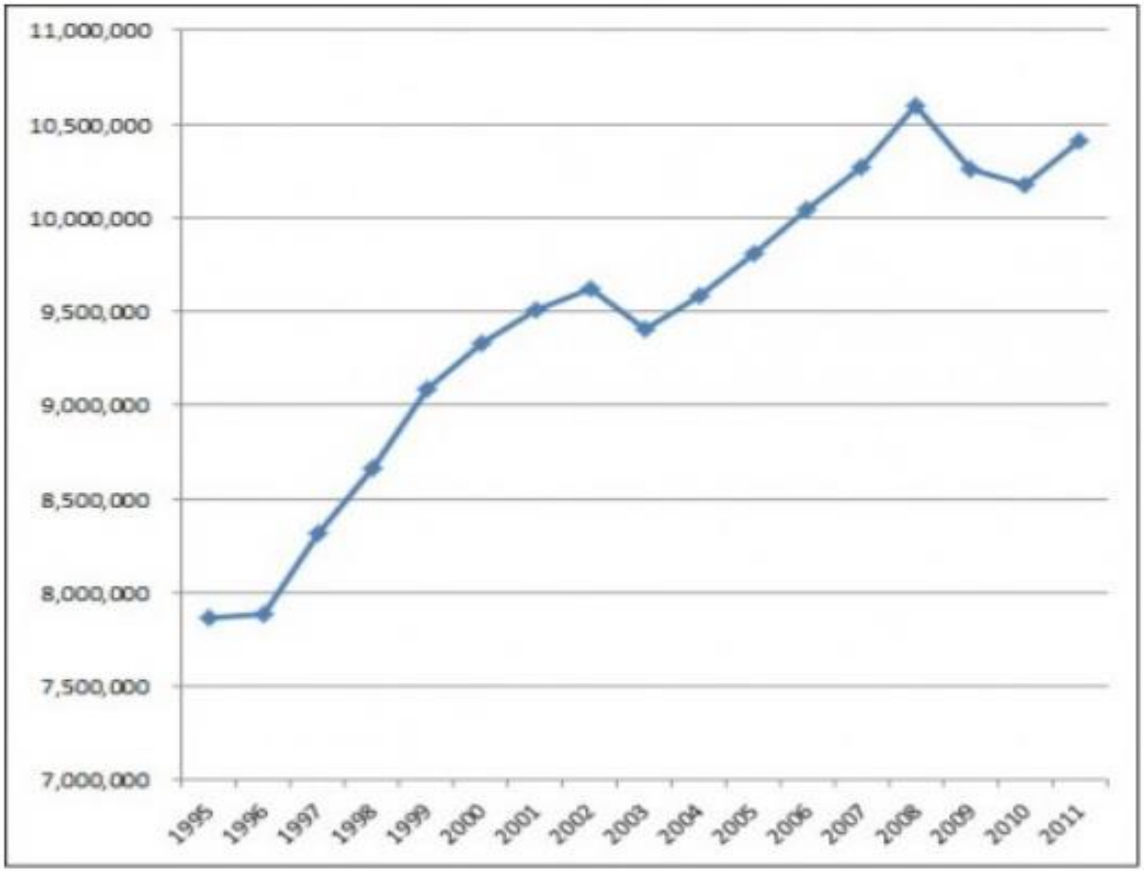


Figure 3: Annual Transit Ridership. [Source: American Public Transportation Association (APTA), 2011]

Conversely, while transit share has grown every year from 2000 to 2010, it cannot meet the need seen in the huge demand for public transit. And as Figure 4 indicates, its share of total travel continues to fall. Data from the U.S. Census and Nationwide Personal Transportation Survey (NPTS) support that conclusion.

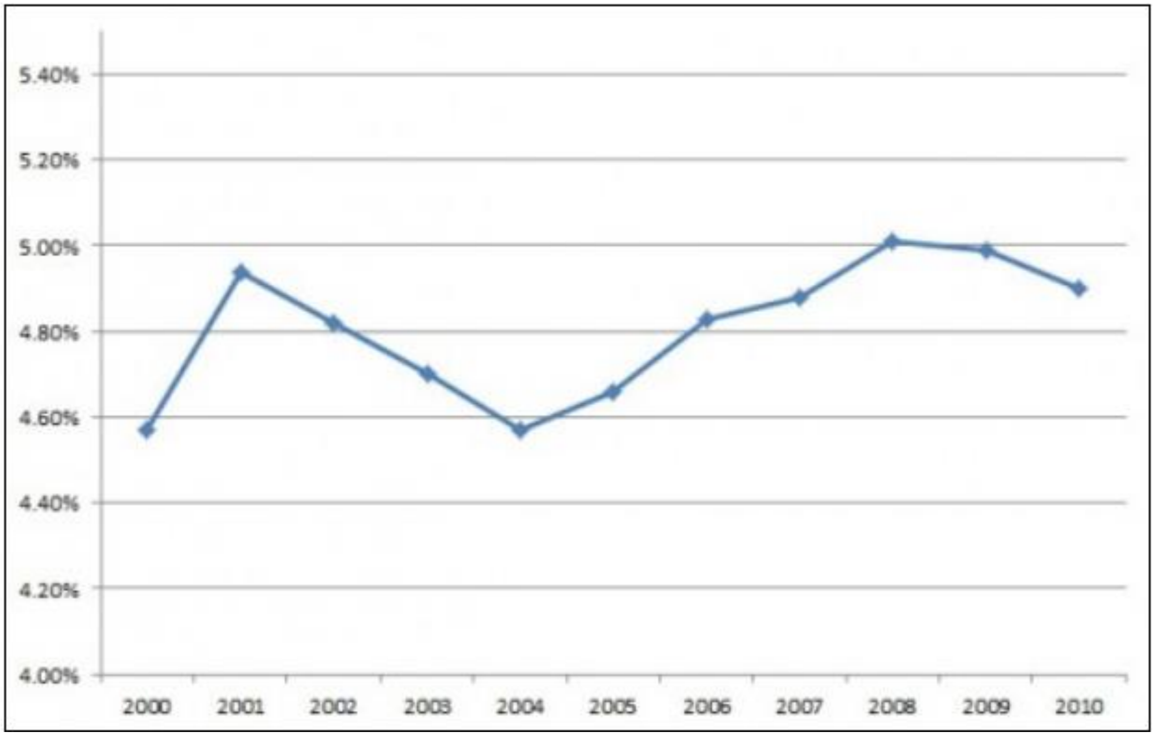


Figure 4: Transit Mode Share. [Source: American Public Transportation Association (APTA), 2011]

The Greater Richmond Transit Company (GRTC) is the primary public transportation provider in Richmond, VA. It operates a hub-and-spoke system and covers the downtown area near the Virginia Commonwealth University (VCU) Health campus and government buildings along Broad Street, but provides services only to Richmond City, parts of Henrico County and Chesterfield County (Figure 5).

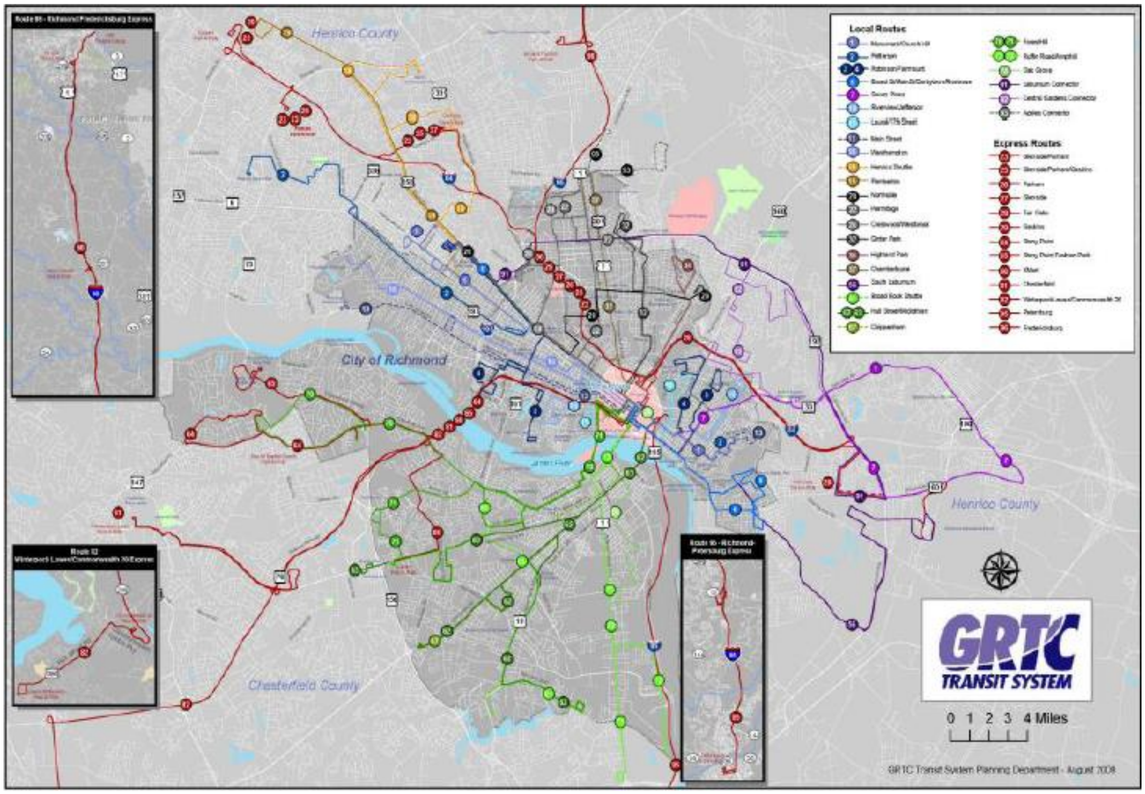


Figure 5: Richmond Greater Richmond Transit Company (GRTC) Bus Route Map. Comprehensive Operations Analysis (2008) (Source: GRTC, 2008)

Some main corridors and high transit demand areas still lack transit service and require transport infrastructure and transport routes (Figure 6). As Blumenberg and Shike note "lack of fair and appropriate transport accessibility might result in a spatial mismatch between social groups and social benefits" (Blumenberg and Shiki, 2003).

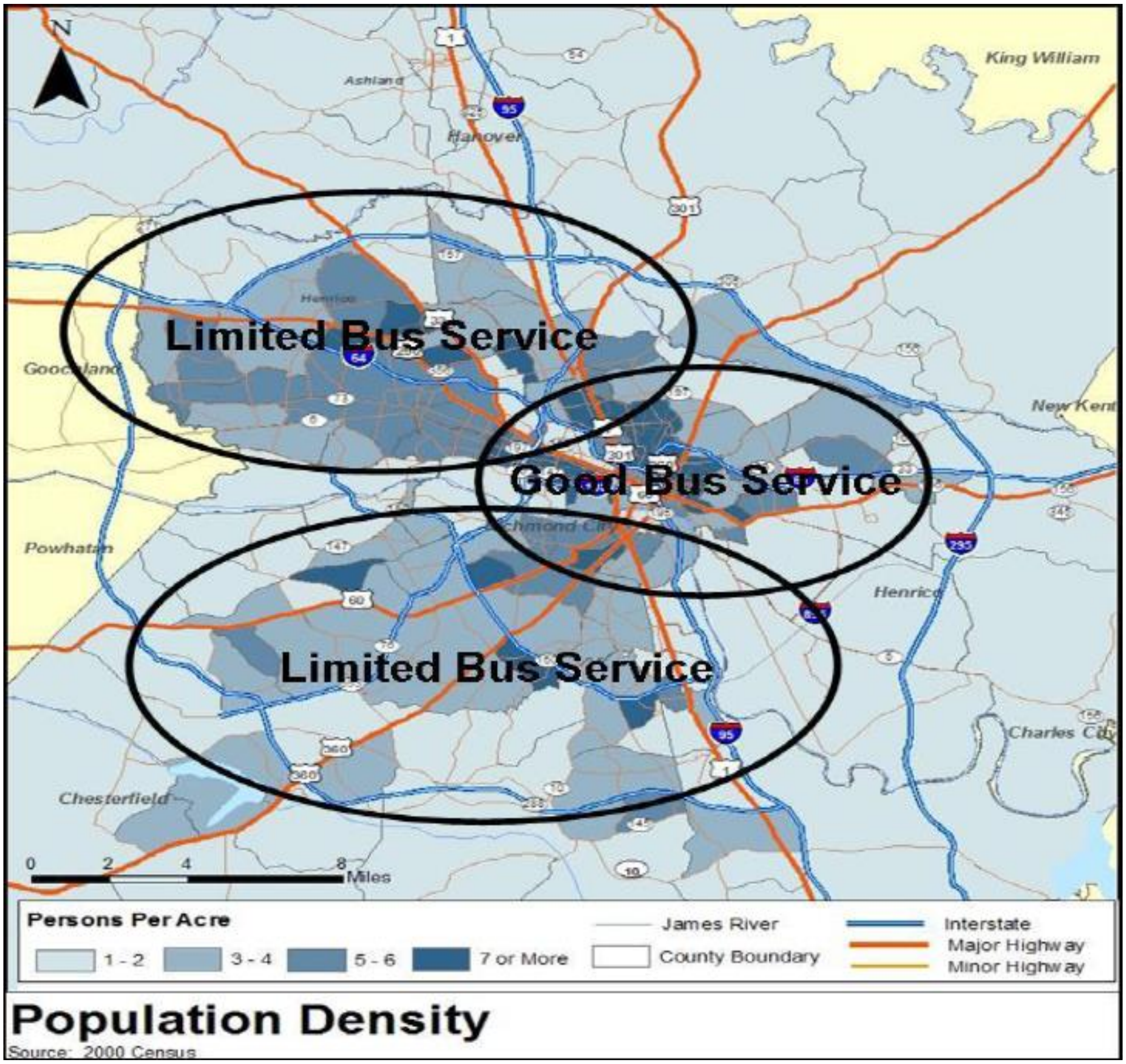
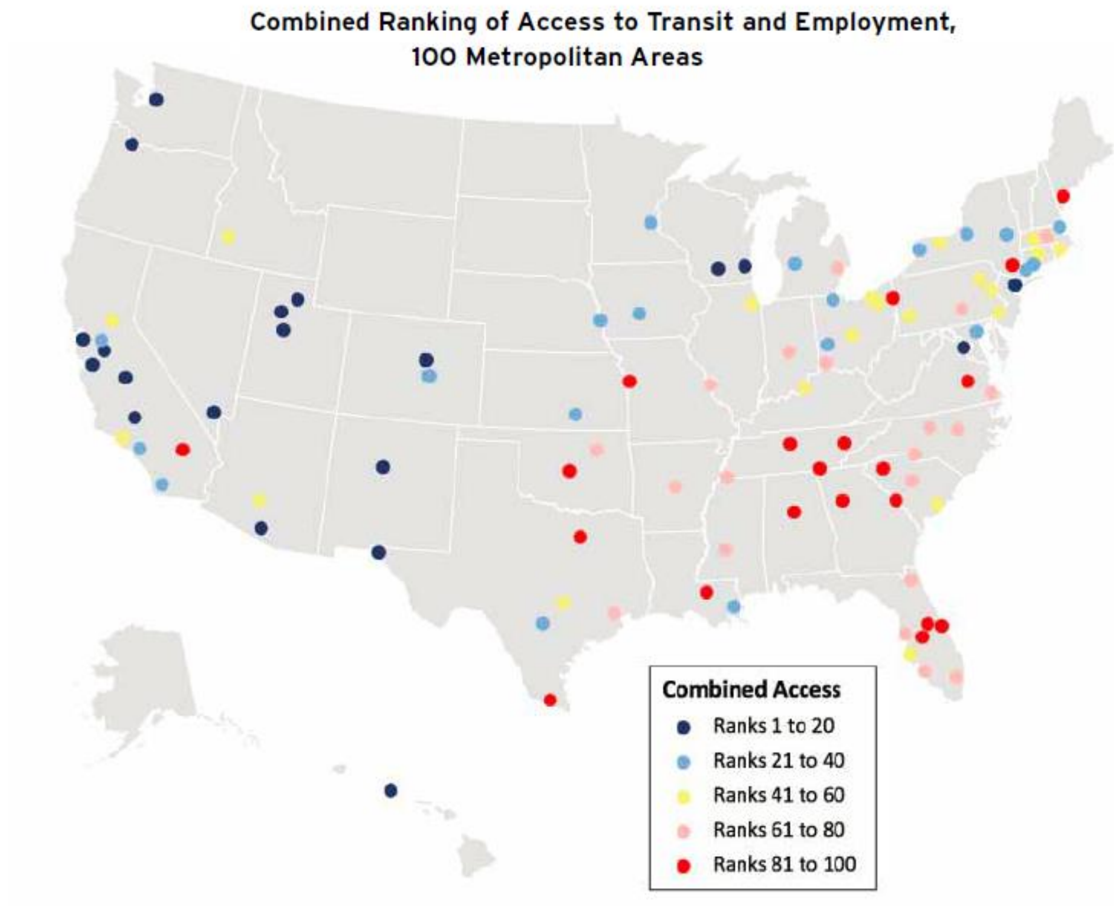


Figure 6: Bus Service Areas and Population Density. Comprehensive Operations Analysis (2008) (Source: GRTC, 2008)

Because of these issues, the Richmond metropolitan area ranks No. 95 out of the 100 metropolitan areas in the U.S. in terms of share of working-age residents with access to transit (Tomer et al., 2011) (Figure 7). To relieve and solve these problems, GRTC and Richmond's local transit agencies completed transit plans, such as Transit Development Plan and Comprehensive Operations Analysis (COA), to provide a series of recommendations and plans to improve and optimize the existing bus routes and build a transfer hub. Richmond Regional Planning District Commission (RRPDC) made its final technical report of the Richmond Regional Mass Transit Study (RRMTS) and cooperated with VCU to research the four main transportation corridors of Richmond.



Source: Brookings Institution analysis of transit agency, Nielsen Pop-Facts 2010, and Nielsen Business-Facts data

Figure 7: Combined Ranking of Access to Transit and Employment, 100 Metropolitan Areas (Source: Tomer et al., 2011)

However, the studies from Richmond's local transit and planning agencies were broadly written. I am going to identify the most vital variables and relative factors to analyze Richmond city's bus ridership to fill this void. This study researching city transportation is valuable to Richmond City development and policy modification. Because "the major objectives of urban transportation policy are the achievement of sound land use patterns, the assurance of transportation facilities for all segments of the population, the improvement of overall traffic flow, and the meeting of total transportation needs at minimum cost. Only a balanced transportation system can attain these goals - and in many urban areas this means an extensive mass transportation network fully integrated with the highway and street system" (U.S. Congress, Senate, 1962).

2.2 Previous study of factors impacting transit ridership

Factors such as population and employment distribution and density, service, fare, work locations and hours, number of automobiles and transit waiting time influence transit ridership.

European Commission on Transportation Research (ECTR) categorizes two groups of direct strategies and indirect strategies to distinguish the similar variables. Direct strategies influence transit ridership efficiently and effectively, as do as external factors. Based on the ECTR, direct strategies include fare, service quality, marketing, and facilities (Table 1 and Table 2).

Table 1: Direct Strategies. (Source: European Commission Transportation Research, 1996)

Direct Strategies	
Pricing	Fare Levels Ticketing Regimes/Fare Structure Ticketing Technology Subsidy Regime
Service	Extensiveness of Routes Distance to/from Stops Service Frequency/Travel Time Operating Hours Fleet Size
Service Quality	Vehicle Characteristics Bus/Rail Stop Quality Interchange Quality Quality/Number of Staff
Priority Measures	Link Priority/Right-of-Way Junction Priority
Regulatory Regime	Market Regulation Operational Regulations Quality Regulations
Information	Information Provision Publicity/Promotion
Others	Park-and-Ride Integrated Approach

Table 2: Indirect Strategies (Source: European Commission Transportation Research, 1996)

Indirect Strategies	
Car Ownership	Taxation of Car Ownership Restrictions on Car Ownership
Car Use and Area-Specific	Traffic Calming Access Restrictions Road Pricing Parking Availability Cost of Parking Parking Enforcement
Car Use and General	Fuel Tax Restrictions on Car Use Car Vehicle Specification
Others	Information on Traffic Conditions Land use Planning Telecommuting/Tele-Shopping Flexible Working Hours Increase in Road Capacity Improvements to Non-Motorized Modes

Taylor and Fink (2002) state transit ridership factors can be categorized into two groups: traveler attitudes and perceptions, and environmental system, and behavioral characteristics. The category of environmental system and behavioral characteristics, includes aggregated and disaggregated studies like the unit of research and metropolitan and big cities variables and individual traveler choice decisions. They also say the research of travelers and operators attitudes and perceptions are descriptive analyses because transit operators often develop descriptive analyses for marketing and fare policy. But the research of environments, systems and behaviors are causal analyses (Figure 8). "Descriptive and causal analyses each have advantages and disadvantages. Descriptive analyses are based on sets of often interesting and rich qualitative data from surveys of and interviews with transit operator staff. Thus, these studies focus on what transit managers believe affect transit ridership" (Taylor and McCullough, 1998).

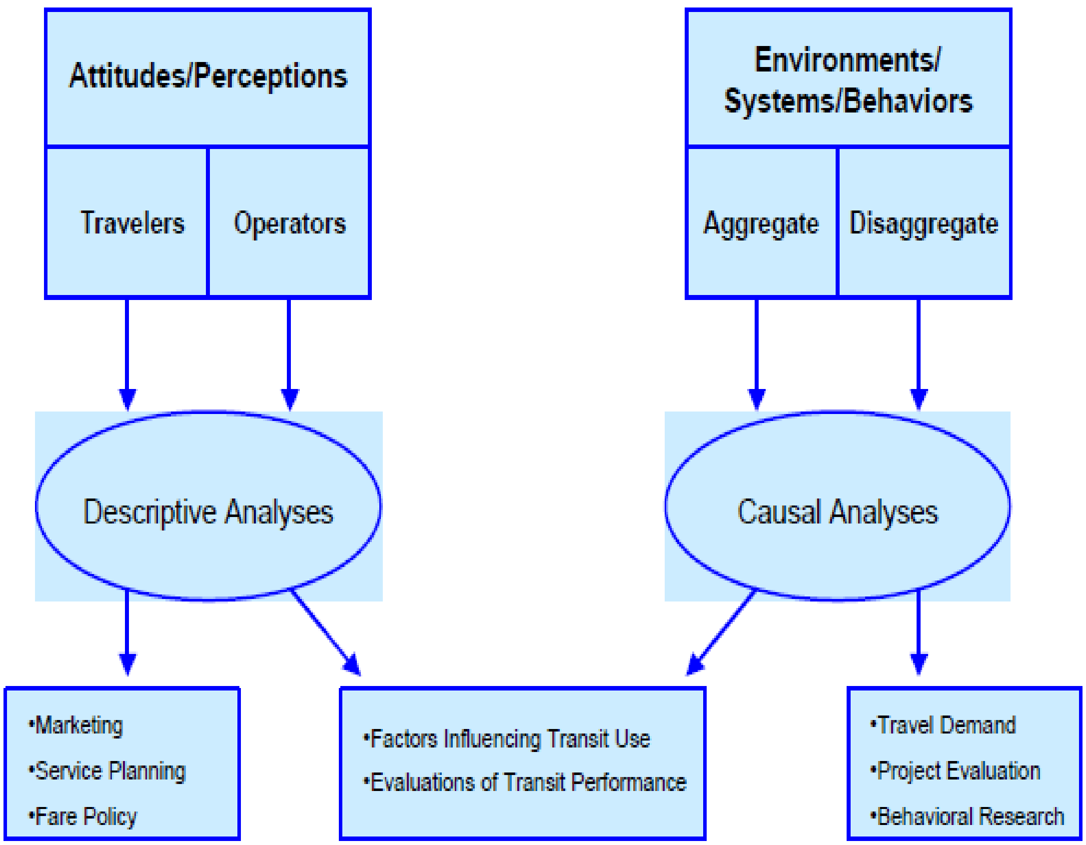


Figure 8: Studies of Transit Ridership. (Source: Taylor and Fink, 2002)

2.3 Internal and external factors

What I talk about the descriptive and causal analyses can be categorized into external factors and internal factors. Although they are named external factors and internal factors, actually they have a big relevance and affect each other. For instance, as a result of an increased population or employment density in the study area, the transit services also change. And if ticket fares are reduced, ridership will grow and the transit services also change.

Both internal and external factors play a significant role in influencing transit ridership. Internal factors are things like public transit service, fare structures, bus route design and schedules, bus size, and policies. External factors are population and employment situation, job distribution, traffic congestion, parking distribution and costs and gas price. "Public transit ridership is influenced by a variety of factors, both internal and external to the transit system. Internal factors are those under the purview of transit managers and policy boards, such as the level of service provided, fare structures and levels, service frequency and schedules, route design, and service area size. External factors, in contrast, are those outside of a transit agency's control-such as population and employment growth, residential and workplace location-and factors that influence the relative attractiveness of transit, such as gasoline prices and parking costs" (Mineta Transportation Institute, 2002).

Dajani and Sullivan (1976) use a causal model to estimate public transit ridership with 1970 census data. The variables include median household income, density, transit service quality, percentage of downtown city workers, percentage of African-American population and auto ownership.

Ben-Akiva and Lerman (1985) find that waiting time, especially at a stop or station impacts the transit ridership. Similarly, “People don’t mind waiting for a bus if they know how long it’s going to be. Even if they have to waste the time, at least they know it’s going to be 15 minutes. Otherwise they’re sitting there thinking the bus will be along in about two minutes, and when it doesn’t show, then they start getting frustrated” (Duffy, 2002).

Cervero (1990) states when considering the relation between transit service and riders and between ticket fare and riders, riders pay more attention to public transit service. So the public transit service is more important than ticket fare. That is valuable to transit agents and operations.

McLeod, Flannelly and Behnke (1991) use data for the range from 1956 to 1984 of Honolulu, Hawaii to calculate multivariate variables time series regression models. In their models, using revenue trips, have five independent variables: kinds of jobs, adjusted per capita income, fares, and different size of the transport and a series of accounting by different disruptions. They find the gasoline price has a small impact on public transit ridership.

McLeod, Flannelly and Behnke (1991) find number of tourists, gasoline prices and free ticket riders are not important factors influencing public transit ridership. They use the number of passenger vehicles and other variables in two time-series regression models.

Liu (1993) builds a regression model based on the data of Portland, Oregon. He uses the model to examine and evaluate per capita transit trips. The factors in his model are per capita transit capacity, per capita passenger car registrations, per capita transit subsidies, per capita income, percent of population residing in the central city, metropolitan area population, motor vehicle fuel prices, a time-trend variable for a period 1929-1990, annual total transit miles, average passenger fare, total employment in the Portland metropolitan area, and the effects of World War II. His results that show per capita income and auto ownership are important.

Liu (1993) and Kain and Liu (1995, 1996) use regional employment as variables in their regression analyses. Chung (1997) states employment and regional development play a vital role in the Chicago Transit Authority (CTA) system.

The female labor force is increasing, more and more women use private vehicles rather than public transit, but women were relying on public transit in the past (Rosenbloom and Burns, 1993; Hayghe, 1996).

Car ownership has a huge impact on improving public transit ridership. High-income passengers have cars and low-income passengers without cars are relying on the public transit (Kain and Liu, 1995). The effect of income has similarities with car ownership.

Nelson and Nygaard (1995) find in all of the 40 land use and demographic variables, housing and employment density per acre are most important in transit demand. They can explain 93 percent of the variation in transit demand.

Kain and Liu (1995) state the average ticket fares, revenue vehicle miles of service, regional employment levels and car ownership situation have huge impacts on public transit ridership.

In his regression models, Gomez-Ibanez (1996) used both internal (ticket fare and transit service policies) and external (employee income, population) factors to study their influences on transit ridership and deficiency reduction for the Massachusetts Bay Transportation Authority (MBTA) in Boston. His models find external factors play a vital role in Boston. For instance, the ratio of downtown jobs and the percentage increase in per capita income affect public ridership a lot. Conversely, the transit service level and the fare influence can be ignored in Boston.

Kain and Liu (1996) research and analyze the main factors which influence the level of public transit ridership based on the data for 184 systems from 1960 to 1990, 30-year long range. They use regression models to study 1960-1970, 1970-1980 and 1980-1990 ridership factors. In their regression model, they use the independent variables both in

public and private system such as revenue miles of service supplied, population, employment, population density, fraction of carless households, fare levels. And the models show ridership changes between 1980 and 1990 had $R^2 = 0.75$ or above.
For the race, Blacks and Hispanics are more dependent on public transit (Pisarski, 1996; Rosenbloom, 1998). In this study I choose the Black rate as an independent variable, because there is a high proportion of Blacks in Richmond City. Previous literature shows low-income households and households without access to vehicles depend on public transit and previous research also documents how age, ethnicity and gender influence public transit ridership.

Income is a factor to influence public transit ridership. More middle-income and high-income people don’t choose public transit, but low-income passengers are increasing (Pucher et al., 1998).

Based on the data of five cities (Seattle, Portland, Salt Lake City, Denver, and San Diego), Spillar and Rutherford research the relationship between city resident density and public transit ridership and the relationship between income and public transit ridership. They use total population, annual income situation and research area acre information to find out that density has a huge impact on transit ridership in the low-income area, but has little effect on the high-income group in public transit ridership (Spillar and Rutherford, 1998).

Based on data of 85 Canadian city transit agencies from 1992 to 1998, Kohn (2000) examines the vital explanatory variable to forecast public transit ridership and then states that average fares and revenue vehicle hours are the two key variables. In his model, he analyzes demographics, hours of transit service, fare structure, vehicle statistics, energy consumption, employment situation, passenger statistics, and revenue. Two variables, average fares and revenue vehicle hours explain all variation in the public transit ridership ($R^2 = 0.97$); other variables are meaningless.

In his research, Kohn first picks up average fare in the regression model but R square shows this is not important. When he chooses population of the research area, the R square value increases but it is still low. The second step shows the population of the research area is more important than fare. He picked these two in one model and the R square value is 0.51. And then more independent variables were added in his model to test the relationship: "For each year of data (to account for any differences on an annual basis), for cities that have populations in excess of one million, this dummy variable assumed that larger cities have more comprehensive transit systems, more traffic, a greater dispersion of people geographically, longer commute times, and, perhaps, a greater tendency towards transit ridership, for cities with more than one million urban transit passengers; this dummy variable was similar to the preceding variable for cities with populations in excess of one million; despite the apparent similarity, the correlation between the 2 variables was only 0.19, for cities with populations less than 100,000; this dummy variable assumed that cities with populations less than 100,000 people have less comprehensive transit systems, less population dispersion, shorter commute times and, perhaps, a lower tendency to use public transit than cities with greater populations" (Kohn, 2000).

In his survey, Syed (2000) finds that fare is the least influential factor comparing with transit information, customer and street service, station and on-board safety in passenger considerations.

Kikuchi and Miljkovic (2001) consider the demographic conditions around the bus stops, conditions of the bus stop and the level of transit service to build and research the public transit ridership prediction model by bus stops. Also, Florida Department of Transportation (FDOT) uses t-test in transit ridership evaluation model to evaluate the public transit ridership by route, bus route direction and bus stop buffer characteristics, etc. (FDOT 2004; FDOT 2005).

Residential and employment densities are critical determinants of transit ridership (Taylor and Fink, 2002). And Pushkarev and Zupan (1977) find that there is a positive influence between density and public transit ridership.

Chu (2004) builds a public transit ridership model at the bus stop to study an average weekday boarding with six categories of factors like socio-demographics in the area, Transit level-of-service (TLOS) value, street environment for pedestrians, accessibility to population and employment and competition with other TLOS stops. “TLOS based on transit availability and mobility and demographic characteristics, pedestrian environment, interactions with other modes, and competition from other bus stops were considered and found to play a significant role in predicting the ridership” (Srinivas and Mahesh, 2012)

And most exterior factors are socioeconomic, and while there is no obvious line to distinguish interior and exterior factors, external factors are more important than interior factors. “Although a wide array of factors clearly influence transit patronage, our analysis finds that the most significant factors influencing transit use are external to transit systems” (Mineta Transportation Institute, 2002).

Chen and Suen (2010) use the data of the year 2000 Census Transportation Planning Package (CTPP) to analyze and estimate production-side and attraction-side transit ridership by transportation analysis zones (TAZs) in Richmond. And they use both internal and external factors which affect transit demand as independent variables. As a result, they find bus stops per worker, auto density and population density are three most important factors in production-side analysis (Table 3). In the attraction-side analysis, percentage of zero-vehicle workers, and percentage of workers whose households are below poverty status level are key factors (Table 4).

Table 3: Regression Model Parameter Estimates in Production Side (Source: (Chen and Suen, 2010))

Model	B	Std. Error	Beta	t	Sig.
(Constant)	-.024	.028		-.866	.388
Bus stop/worker	1.247	.087	.636	14.399	.000
Automobile density	-.015	.002	-.453	-6.385	.000
Population density	.007	.002	.359	4.658	.000
Percentage of the workers whose households are below poverty status	.363	.055	.311	6.623	.000

Percentage of the disabled workers	-.423	.111	-.161	-3.794	.000
Percentage of the senior workers	.104	.034	.141	3.033	.003
R square = 0.781					

Table 4: Regression Model Parameter Estimates in Attraction Side (Source: (Chen and Suen, 2010))

Model	B	Std. Error	Beta	t	Sig.
(Constant)	-.052	.017		-3.038	.003
Percentage of the workers whose households have zero vehicles	.419	.074	.396	5.634	.000
Percentage of the workers whose households are below poverty status	.211	.071	.216	2.975	.003
Percentage of the workers making trips during a.m. and p.m. peak periods.	.088	.026	.205	3.364	.001
Percentage of the disabled workers	.100	.042	.156	2.373	.019
Bus stop/worker	.190	.081	.156	2.337	.021
R square = 0.497					

In summary, most of the literature researches both internal and external factors, such as household income, density, transit service quality, vehicles, fare, employment and population. This study will examine public transit ridership using these factors in Richmond City and also add gender and bus lines as new independent factors which they have not been used in past research.

CHAPTER 3: METHODOLOGY

3.1 Method and data collection

This study will be conducted based on literature reviews and a rigorous data analysis on the transit ridership influenced by transit and group-level socioeconomic variables. In this study, geographic information system (GIS) is used to map factor indication and bus stop distribution by block groups and Statistic Correlation and Regression model to analyze the main factors (Total population, Households, Race, Bus stops count, etc.) which influence public transit ridership significantly.

The principal data source is 2009-2013 American Community Survey 5-Year Estimates of Richmond City and 2000 Census Transportation Planning Package (CTPP). And the dependent and independent variables are all from 2009-2013 American Community Survey 5-Year Estimates of Richmond City. According to the 2007 household survey conducted by GRTC (2008), 86 percent of fixed route service is provided to downtown area and most local bus routes exist and support downtown area. More than 80 percent of the ridership was made up by local bus routes, so the research is concentrated on Richmond City.

3.2 Why use these methods

Regression analysis is a statistical tool for the investigation of relationships between variables. Researchers collect data on the underlying variables of interest and employ regression to estimate the quantitative effect of the causal variables upon the variable that they influence. GIS is used to show the spatial distribution of each socioeconomic variable by block group level to display the different distribution. Many researchers use these methods to analyze the relationship between independent variables and dependent variables. Therefore, these two methods are used to analyze the relationship between one dependent variable and 14 independent variables.

3.3 Define variables

Public transit provides a convenient and low-cost mode for residents. In this study, the dependent variable is the number of passengers boarding at the bus stop. Bus stops are typically located according to a local transit agency's service decisions and standards.

For the independent variables, comparing with the strategies from transit agencies, macroeconomic conditions like socioeconomic factors influence public transit ridership more than internal factors. Most external factors are socioeconomic factors. No obvious line separates internal and the external factors, but of the two external factors are more important.

Therefore, based on literature review, independent variables used in previous literature not directly related to public transit ridership are excluded from this study. External factors like population (total population), population density (total persons/acre),employment density (employees/acre), income (median household income) car ownership (the number of vehicles in household), acres (the size of each block group), black ratio (black population/total population), female rate (total female population/ total population),households (total households), household density (households/acre), low-skilled jobs (total low-skilled Employment), low educated people (educational attainment under and not including high school), unemployment rate (total unemployed/total population), and the number of bus lines in each block group are chosen as independent variables.

Table 5 shows both dependent and independent variables.

Table 5: Dependent and Independent Variables

Variable Type	Variable Name	Variable Definition
Dependent Variable	Daily-On	The number of daily number of passengers boarding on bus at any bus stop by block groups
Independent Variable	TotPop	Total population
	Income	Median household income
	Vehicles	The number of vehicles in household
	Popden	Population density: persons/acre
	Huden	Household density: number of housing units per acre, households/acre
	Black ratio	Black ratio: Black population/Total population(all races)

	Acres	The size of each block group
	Female rate	Total female population/ Total population
	LowEduction	Educational attainment (under and not including high school)
	Households	Total households
	EmpDen	Employment Density: employees/acre
	LowSkilled	Total low-skilled Employment(jobs)
	Unemployed Rate	Total unemployed/ Total population
	NoBusLines	The number of bus lines

2007 NAICS Codes: Low skilled job (Construction, Manufacturing, Wholesale Trade, Retail, Transportation and Warehousing)

3.4 Hypothesis

The hypothesis considers the relation between each independent variable (total population and density, acres, household density, black ratio, the number of bus lines income, vehicle count, low-skilled employment and employment density) and the dependent variable (public transit ridership) (Table 6).

Table 6: Hypothesis of independent factors

Positive factors	Negative factors
Total population and Population density Unemployment rate Acres Household and Household density Bus line count Low education Female rate Black ratio Low-skilled employment Employment density	Income Number of vehicles

In the hypothesis, total population, population density, unemployment rate, acres, household and household density, bus line count, low education, female rate, black ratio, low-skilled employment and employment density are assumed to have positive impacts on the number of daily number of passengers boarding a bus at any bus stop by block groups. Income and number of vehicles have negative impacts on the dependent variable.

CHAPTER 4: ANALYSIS

4.1 Mapping dependent and independent variables

For the group of variables utilized in the statistics model in this study, first they are generated by GIS to display in the maps to show each variable situation and distribution. Because of the data limitation, I don't collect all the block groups' data and there are no data in the blank block groups. Following are the dependent and independent variables which are manipulated by GIS. Daily-On (Figure 9), Total population (Figure 10), Income (Figure 11), Car ownership (Figure 12), Population density (Figure 13), Household density (Figure 14), Black ratio (Figure 15), Acres (Figure 16), Bus line count(Figure 17), Female rate(Figure 18), Low education population (Figure 19), Households (Figure 20), Employment density (Figure 21), Low-skilled jobs (Figure 22) , Unemployed rate(Figure 23).

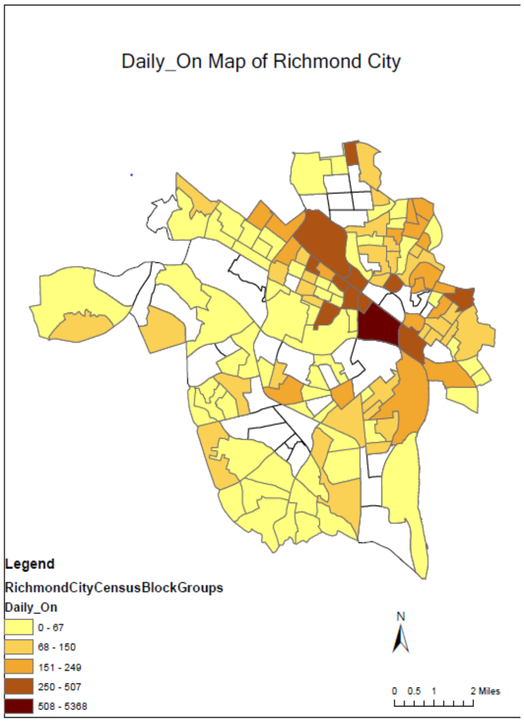


Figure 9: Daily-On

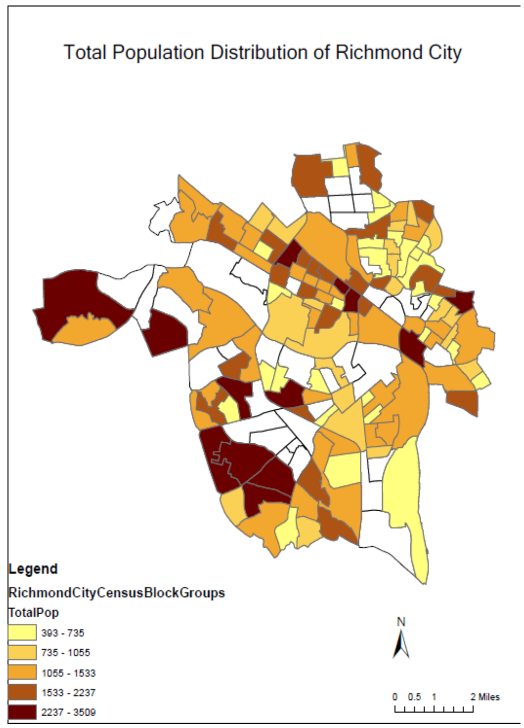


Figure 10: Total population

Some downtown areas are the most concentrated areas of daily-on boarding.

Population is mainly distributed in the west and south of Richmond city and some downtown areas.

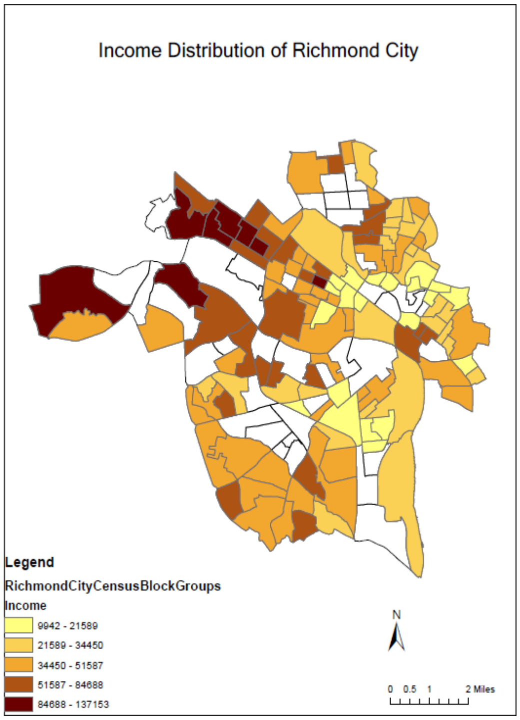


Figure 11: Income

High-income population is mainly distributed in the northwest and south of Richmond city.

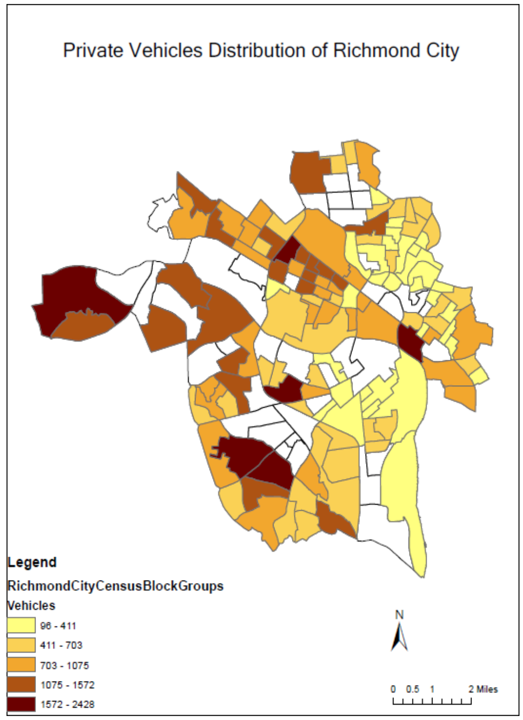


Figure 12: Vehicles

Some downtown areas, the south and west of Richmond city have a large number of private cars.

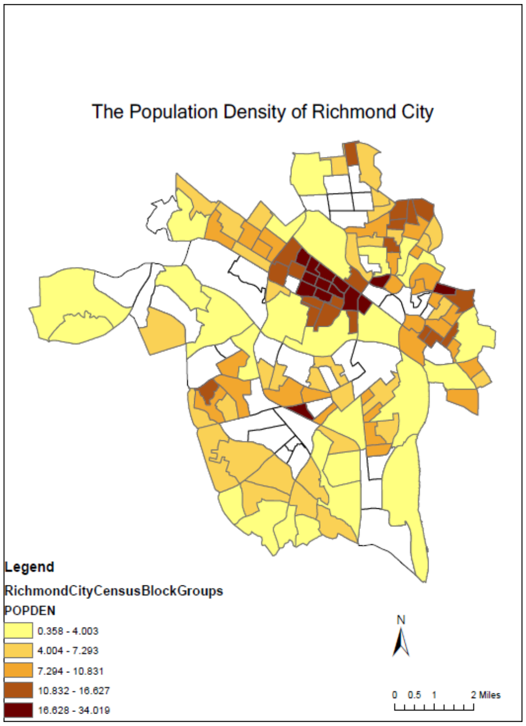


Figure 13: Population Density

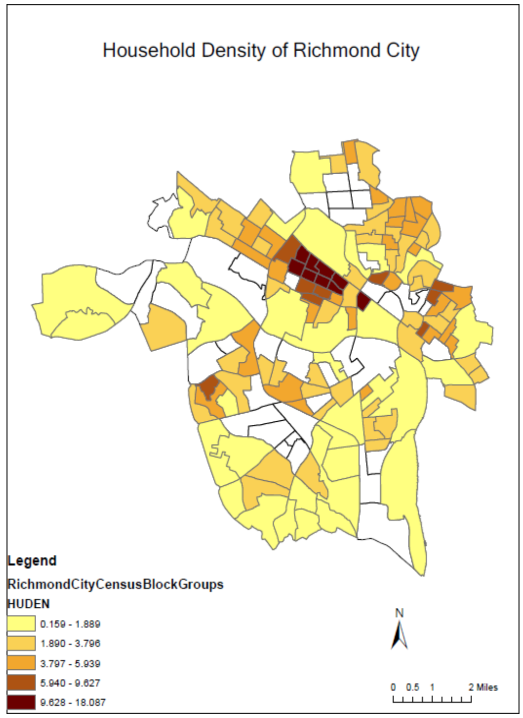


Figure 14: Household Density

Some downtown areas and northeast of Richmond city have much greater population density.

Some downtown areas and northeast of Richmond city have much greater household density.

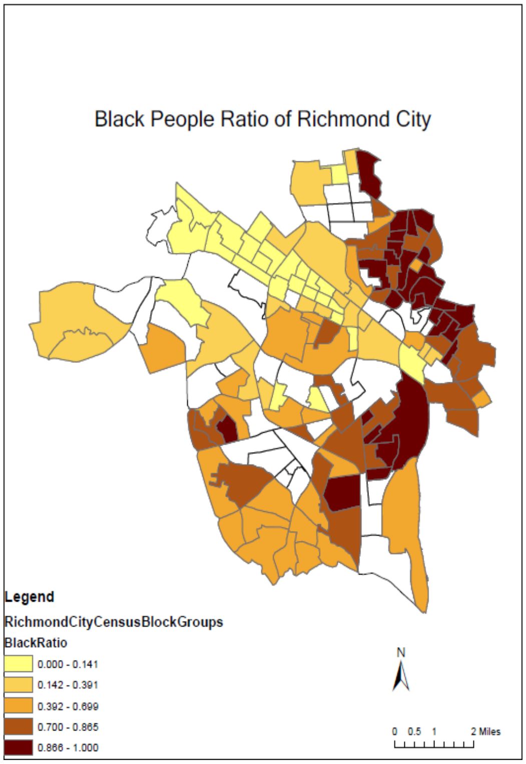


Figure 15: Black Ratio

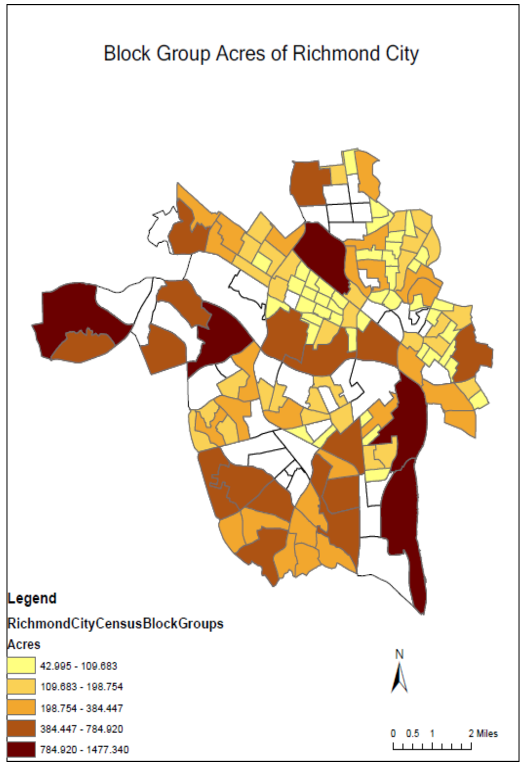


Figure 16: Acres

A larger proportion of blacks are in the northeast and south of Richmond city.

Blocks in the central, southeast and west of Richmond city are much larger.

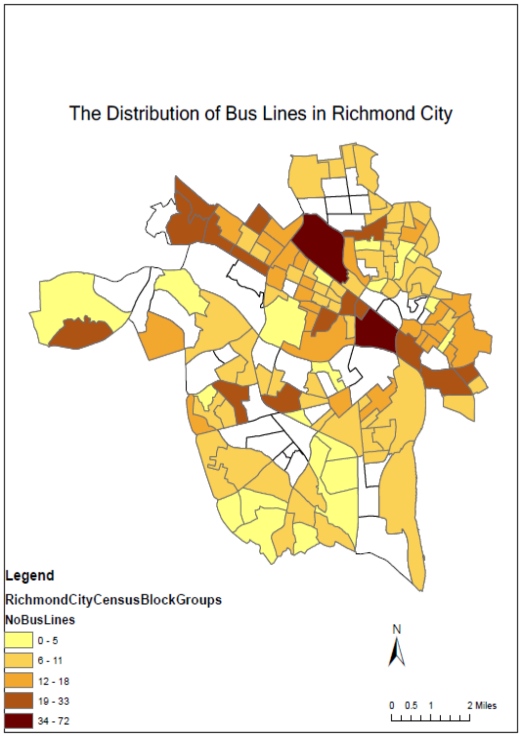


Figure 17: Bus line count

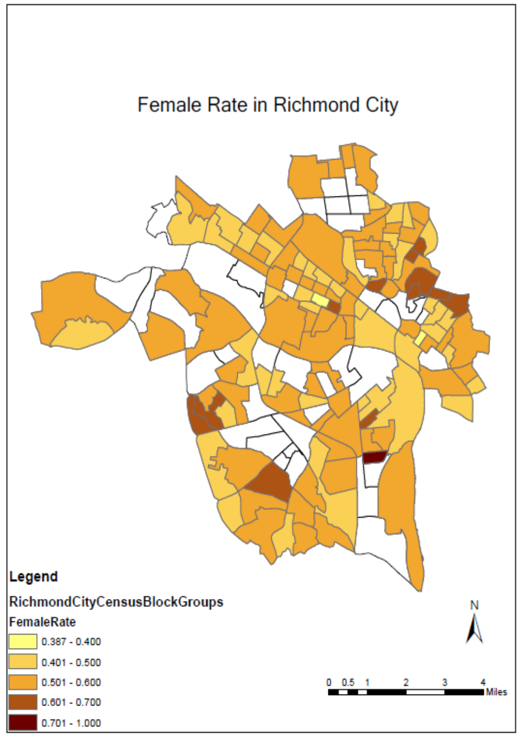


Figure 18: Female Rate

Bus lines are mainly located in the northwest of Richmond city and downtown areas.

There is not much difference of distribution of female rate in each block of Richmond city.

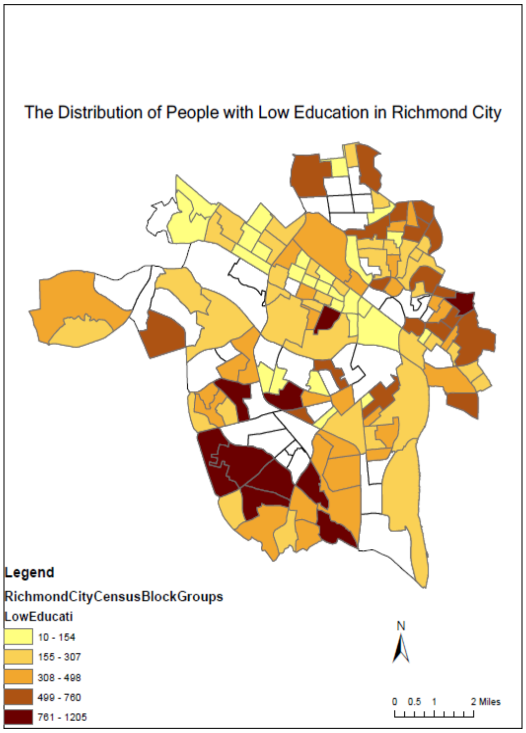


Figure 19: Low Education Population

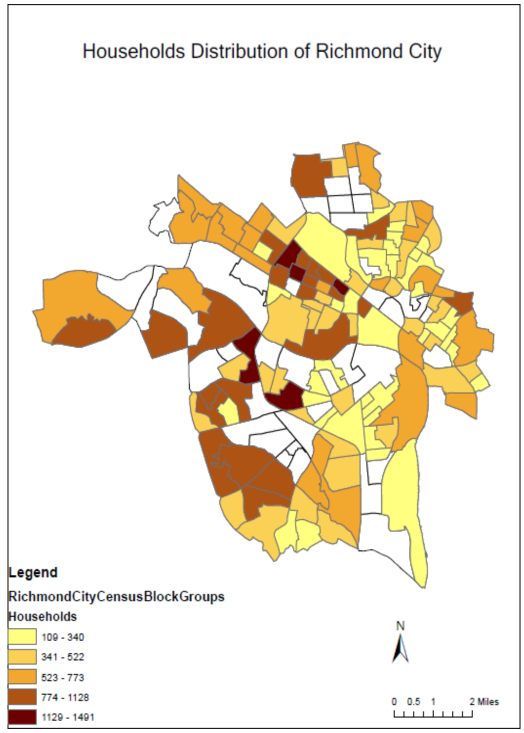


Figure 20: Households

Low-education population is mainly distributed in the south and east of Richmond city.

Households are mainly distributed in the central and southwest of Richmond city.

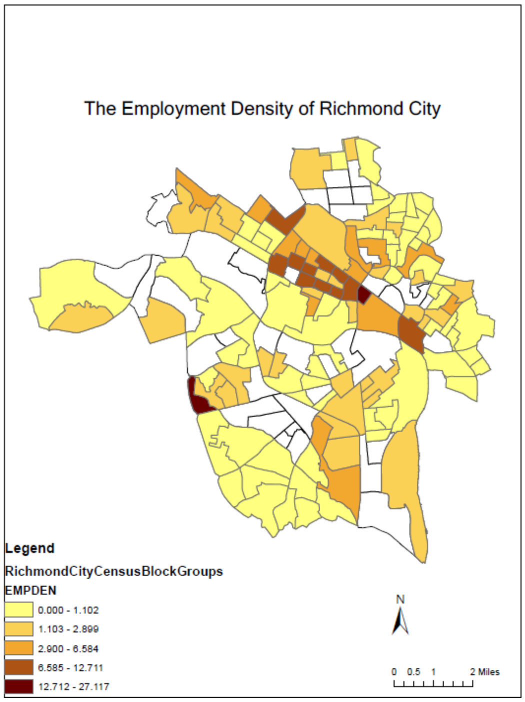


Figure 21: Employment Density

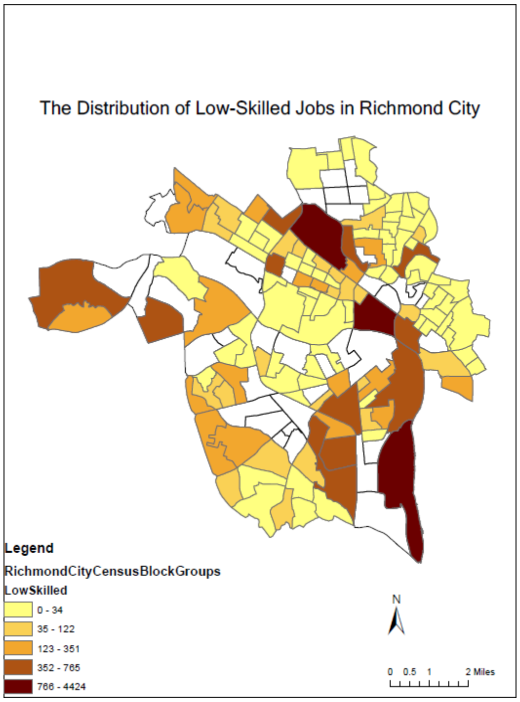


Figure 22: Low-Skilled Employment

Some downtown areas, some north and south of Richmond city have greater employment density.

Low-skilled jobs are distributed in the north and southeast of Richmond city and some downtown areas.

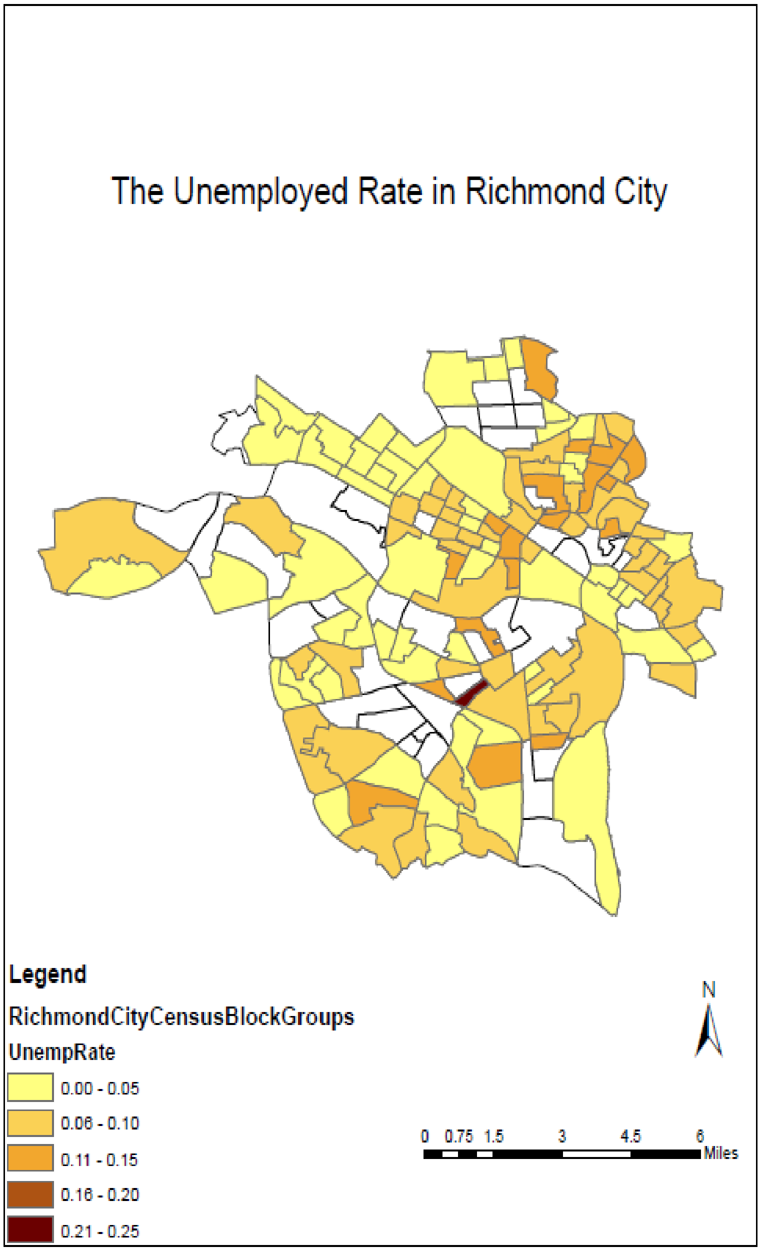


Figure 23: Unemployment Rate

Some areas of north and south of Richmond city and some downtown areas have larger proportion of unemployed.

4.2 Statistics Model analysis

In order to test the hypothesis, based on the correlation model in the Appendix A, Appendix B and Appendix C, the relationships are as follows:

(1) Total population, acres, employment density, low-skilled employment and bus line count are positive with the dependent variable which are consistent with the hypothesis.

(2) Number of vehicle is positive with the dependent variable which is against the hypothesis.

(3) Income is negative with the dependent variable which is consistent with the hypothesis.

(4) Population density, household density, black ratio, female rate, low education, households and unemployment rate are negative with the dependent variable which are against the hypothesis.

In the beginning, I ran the variables in both ways (original and log transformed). But the results show almost no difference between the two ways and the R square is a little bit lower in the log transformed model. So finally I decided not to use log transformed variables. Only original variables are used in my statistical analysis.

In the correlation model summary in the Appendix A, Appendix B and Appendix C, based on the Pearson Correlation and Sig, I exclude two independent variables (Popden, Households) which can be represented by Huden and Vehicles.

In the regression model, there are one dependent variable and twelve independent variables entered, but the stepwise regression model excludes 10 less significant independent variables and there are 2 most important independent variables retained, NoBusLines and Income (Table 7).

Table 7: Regression model summary and parameter estimates

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	NoBusLines	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).
2	Income	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).

Dependent Variable: Daily_On

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics	
					R Square Change	F Change
1	.699[a]	.488	.484	350.524	.488	115.457
2	.711[b]	.505	.497	346.034	.017	4.161

Model Summary

Model	Change Statistics		
	df1	df2	Sig. F Change

1	1	121	.000
2	1	120	.044

a. Predictors: (Constant), NoBusLines

Predictors: (Constant), NoBusLines, Income

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	14185862.496	1	14185862.496	115.457	.000[b]
	Residual	14866940.154	121	122867.274		
	Total	29052802.650	122			
2	Regression	14684086.539	2	7342043.269	61.317	.000[c]
	Residual	14368716.112	120	119739.301		
	Total	29052802.650	122			

a. Dependent Variable: Daily_On

b. Predictors: (Constant), NoBusLines

Predictors: (Constant), NoBusLines, Income

Table 8: Regression Model Parameter Estimates

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-281.846	51.192		-5.506	.000
	NoBusLines	38.401	3.574	.699	10.745	.000
2	(Constant)	-169.619	74.705		-2.271	.025

	NoBusLines	38.407	3.528	.699	10.886	.000
	Income	-.003	.001	-.131	-2.040	.044

Dependent Variable: Daily_On

Excluded Variables[a]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	TotalPop	-.094[b]	-1.415	.160	-.128	.948
	Income	-.131[b]	-2.040	.044	-.183	1.000
	Vehicles	-.126[b]	-1.922	.057	-.173	.956
	HUDEN	.033[b]	.503	.616	.046	.992
	Acres	.001[b]	.014	.989	.001	.988
	FemaleRate	-.003[b]	-.038	.969	-.004	.992
	LowEdu	-.025[b]	-.386	.700	-.035	.993
	EMPDEN	-.017[b]	-.259	.796	-.024	.949
	UnempRate	.070[b]	1.065	.289	.097	.974
	BlackRate	.096[b]	1.430	.155	.129	.934
	LowSkilled	.006[b]	.077	.939	.007	.748
2	TotalPop	-.106[c]	-1.610	.110	-.146	.941
	Vehicles	-.090[c]	-1.279	.203	-.116	.832
	HUDEN	.022[c]	.336	.738	.031	.984
	Acres	.020[c]	.306	.760	.028	.968
	FemaleRate	-.032[c]	-.490	.625	-.045	.946
	LowEdu	-.080[c]	-1.162	.248	-.106	.877
	EMPDEN	-.025[c]	-.377	.707	-.035	.946

UnempRate	.017[c]	.236	.814	.022	.799
BlackRate	.022[c]	.261	.795	.024	.592
LowSkilled	-.006[c]	-.077	.939	-.007	.744

a. Dependent Variable: Daily_On

b. Predictors in the Model: (Constant), NoBusLines

c. Predictors in the Model: (Constant), NoBusLines, Income

In this regression model, it depicts statistically significant relationships between independent variables and daily-on dependent variable to estimate the different importance of key factors.

Overall, based on the stepwise regression model, it can be determined that NoBusLines (variable name: the number of bus lines) and Income (variable name: Median household income) are the most vital factors impacting the amount of daily number of passengers boarding on bus at any bus stop by block groups.

More bus lines is significantly associated with higher levels of bus transit ridership at any bus stop. Conversely, income is negatively related to bus transit ridership.

Table 9: Summary of key impacting variables

Independent Variables	Variable name
NoBusLines	The number of bus lines
Income	Median household income

4.3 Model Validation

The above stepwise regression model has yielded the following estimated equation:

Daily_On = -169.619+38.407*NoBusLines-0.003*Income

For the purpose of model validation, the input data for variables NoBusLines and Income of 159 census block groups [Note: two block groups (GID# 517600302002, and GID# 517600505003) are excluded due to their missing income data] are plugged into the above equation, which yields the modeled Daily_On (reflecting average trend of bus boarding across board) against which the observed Daily_On (reflecting actual bus boarding, which fluctuates around the average trend line) will be compared, and their percentage error will be calculated.

In its Title VI report, GRTC uses 25% (±) as a benchmark to judge if a major service change has occurred. Following the same benchmark, this thesis also assumes that, for a block group:

If the percentage error between observed Daily_On and modeled Daily_On is within 25% (±), the block group is adequately served by bus services, more or less reflecting average trend of bus boarding;

If the percentage error between observed Daily_On and modeled Daily_On is greater than + 25% (above the average trend line), the block group is overserved by bus services. To return to the normal, average trend, the number of bus lines and bus services should be decreased; and

On the contrary, if the percentage error between observed Daily_On and modeled Daily_On is less than -25% (below the average trend line), the block group is underserved by bus services. Therefore, the number of bus lines and bus services should be increased in order to return to the normal, average trend.

It should be noted the above determination of "overserved/underserved" status is not from the strict sense of transit supply and transit demand as defined in the so-called "transit desert" analysis. Instead, it merely compares the observed stop-level bus boarding against the trend line (reflecting the theoretical and average stop-level bus boarding). If GRTC wants to match the observed stop-level bus boarding to the trend line, its service levels and structures need to be properly adjusted.

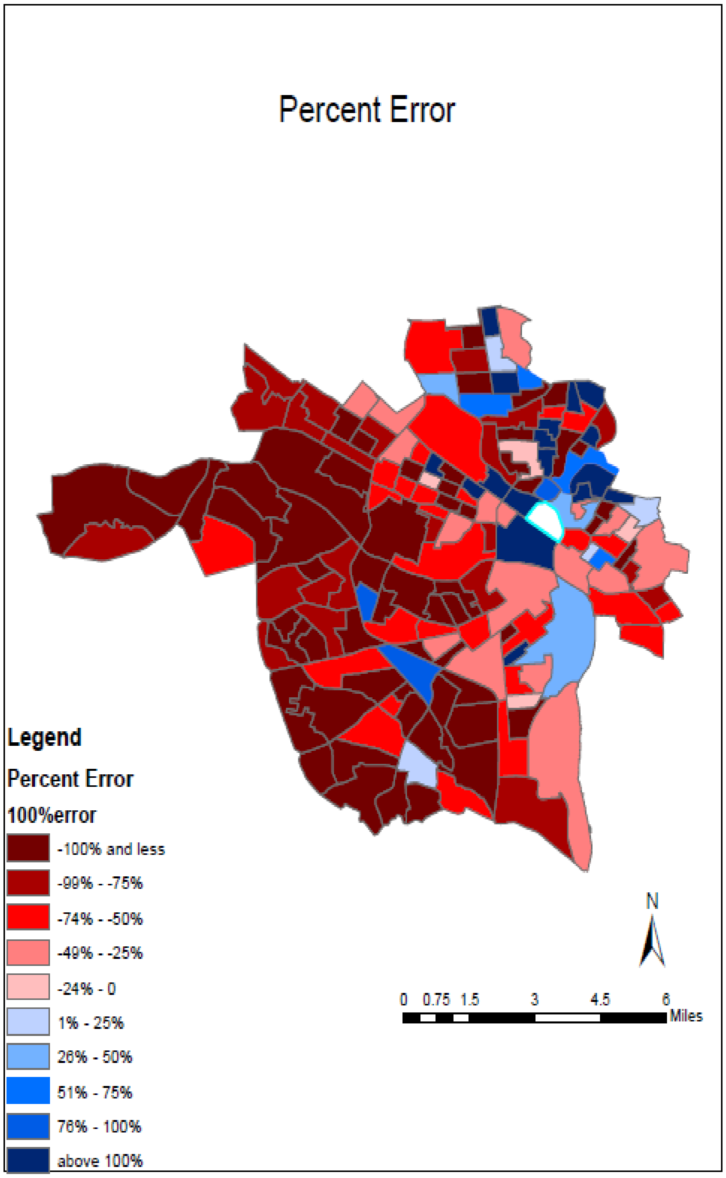


Figure 24: Percent Error by Block Group in Richmond City

Given the above assumption, Figures 24 reveals the following:

First, downtown Richmond and its immediate neighborhood are overserved by GRTC;

Second, the west side and south side of the City are underserved by GRTC; and

Third, the rest of the City is more or less adequately served by GRTC.

Following this line of thought, this thesis recommends that GRTC gradually change the existing hub-and-spoke bus system structure and move some bus services from downtown Richmond to the west side and south side of the City.

CHAPTER 5: CONCLUSION

This study estimates the Richmond City public ridership based on a group of independent variables. With Richmond's high demand for bus transit, how to satisfy the improving bus transit is a challenge problem. Although Richmond GRTC well serves the downtown city area, urban fringe areas like Midlothian, South Side are not well covered and no bus lines cross some suburbs. The existing hub-and-spoke bus transit system needs to be refined and optimized to adapt future development. As the result, I find bus stop count and bus line count definitely impact public transit ridership. Government and local agencies should consider investing in suburb-to-suburb bus transit and optimizing the bus line locations and amount, bus stop locations and number of bus stops.

The analyses presented in this thesis are particularly valuable for local and regional policy-makers to improve public transit ridership and to deal with transit and environmental problems like traffic congestion reduction, crime, civic engagement, the enhancement of economic development, gas conservation and air quality improvement. The evidence and resulting thesis also support GRTC and local planning seeking transportation funding to pursue balanced public transit future plans and land use plans.

I recognize that, because of the data limitation, I did not collect all of the block group data. And some considerable factors like inflation-adjusted per capita income, revenue vehicle miles, fraction of carless house and fare structure in different years will be joined in the future study. Multicollinearity cannot be ignored, because it leads to the result that the coefficient estimates are unstable and some variables difficult to interpret.

APPENDIX A

Correlation model summary
(All Variables)

		Daily_On	Income	Vehicles	POPDEN	HUDEN	BlackRate	Acres	FemaleRate
Daily_On	Pearson Correlation	1	-.130	.026	-.002	-.031	-.090	.078	-.065
	Sig. (2-tailed)		.151	.778	.985	.733	.325	.388	.474
	N	123	123	123	123	123	123	123	123
Income	Pearson Correlation	-.130	1	.353**	-.238**	-.086	-.585**	.141	-.215*
	Sig. (2-tailed)	.151		.000	.008	.346	.000	.119	.017
	N	123	123	123	123	123	123	123	123
Vehicles	Pearson Correlation	.026	.353**	1	.111	.187*	-.521**	.321**	-.080
	Sig. (2-tailed)	.778	.000		.221	.039	.000	.000	.379
	N	123	123	123	123	123	123	123	123
POPDEN	Pearson Correlation	-.002	-.238**	.111	1	.842**	-.212*	-.527**	.077
	Sig. (2-tailed)	.985	.008	.221		.000	.018	.000	.398
	N	123	123	123	123	123	123	123	123
HUDEN	Pearson Correlation	-.031	-.086	.187*	.842**	1	-.333**	-.465**	-.008
	Sig. (2-tailed)	.733	.346	.039	.000		.000	.000	.929
	N	123	123	123	123	123	123	123	123
BlackRate	Pearson Correlation	-.090	-.585**	-.521**	-.212*	-.333**	1	-.032	.244**
	Sig. (2-tailed)	.325	.000	.000	.018	.000		.725	.007
	N	123	123	123	123	123	123	123	123
Acres	Pearson Correlation	.078	.141	.321**	-.527**	-.465**	-.032	1	-.055
	Sig. (2-tailed)	.388	.119	.000	.000	.000	.725		.543
	N	123	123	123	123	123	123	123	123
FemaleRate	Pearson Correlation	-.065	-.215*	-.080	.077	-.008	.244**	-.055	1
	Sig. (2-tailed)	.474	.017	.379	.398	.929	.007	.543	
	N	123	123	123	123	123	123	123	123
LowEdu	Pearson Correlation	-.083	-.341**	.274**	-.084	-.202*	.458**	.165	.217*
	Sig. (2-tailed)	.360	.000	.002	.353	.025	.000	.069	.016
	N	123	123	123	123	123	123	123	123

Households	Pearson Correlation	-.052	.106	.719**	.289**	.490**	-.361**	.133	.019
	Sig. (2-tailed)	.569	.245	.000	.001	.000	.000	.142	.837
	N	123	123	123	123	123	123	123	123
EMPDEN	Pearson Correlation	.141	-.054	.138	.386**	.394**	-.351**	-.127	-.071
	Sig. (2-tailed)	.119	.552	.128	.000	.000	.000	.161	.437
	N	123	123	123	123	123	123	123	123
LowSkilled	Pearson Correlation	.355**	-.065	.033	-.249**	-.233**	-.085	.549**	-.076
	Sig. (2-tailed)	.000	.474	.716	.006	.009	.349	.000	.403
	N	123	123	123	123	123	123	123	123
NoLowSkill	Pearson Correlation	.362**	.031	.155	-.183*	-.184*	-.198*	.420**	-.080
	Sig. (2-tailed)	.000	.730	.086	.043	.041	.028	.000	.382
	N	123	123	123	123	123	123	123	123
UnempRate	Pearson Correlation	-.045	-.418**	-.234**	.210*	.067	.363**	-.117	.142
	Sig. (2-tailed)	.618	.000	.009	.019	.460	.000	.196	.118
	N	123	123	123	123	123	123	123	123
NoBusLines	Pearson Correlation	.699**	.001	.210*	-.035	-.091	-.256**	.111	-.090
	Sig. (2-tailed)	.000	.992	.020	.702	.316	.004	.222	.325
	N	123	123	123	123	123	123	123	123

Correlations

		LowEdu	Households	EMPDEN	LowSkilled	NoLowSkill	UnempRate	NoBusLines
Daily_On	Pearson Correlation	-.083	-.052	.141	.355**	.362**	-.045	.699**
	Sig. (2-tailed)	.360	.569	.119	.000	.000	.618	.000
	N	123	123	123	123	123	123	123
Income	Pearson Correlation	-.341**	.106	-.054	-.065	.031	-.418**	.001
	Sig. (2-tailed)	.000	.245	.552	.474	.730	.000	.992
	N	123	123	123	123	123	123	123
Vehicles	Pearson Correlation	.274**	.719**	.138	.033	.155	-.234**	.210*
	Sig. (2-tailed)	.002	.000	.128	.716	.086	.009	.020
	N	123	123	123	123	123	123	123
POPDEN	Pearson Correlation	-.084	.289**	.386**	-.249**	-.183*	.210*	-.035
	Sig. (2-tailed)	.353	.001	.000	.006	.043	.019	.702
	N	123	123	123	123	123	123	123
HUDEN	Pearson Correlation	-.202*	.490**	.394**	-.233**	-.184*	.067	-.091
	Sig. (2-tailed)	.025	.000	.000	.009	.041	.460	.316
	N	123	123	123	123	123	123	123
BlackRate	Pearson Correlation	.458**	-.361**	-.351**	-.085	-.198*	.363**	-.256**
	Sig. (2-tailed)	.000	.000	.000	.349	.028	.000	.004

	N	123	123	123	123	123	123	123
Acres	Pearson Correlation	.165	.133	-.127	.549**	.420**	-.117	.111
	Sig. (2-tailed)	.069	.142	.161	.000	.000	.196	.222
	N	123	123	123	123	123	123	123
FemaleRate	Pearson Correlation	.217*	.019	-.071	-.076	-.080	.142	-.090
	Sig. (2-tailed)	.016	.837	.437	.403	.382	.118	.325
	N	123	123	123	123	123	123	123
LowEdu	Pearson Correlation	1	.310**	-.281**	-.071	-.082	.165	-.083
	Sig. (2-tailed)		.000	.002	.433	.370	.067	.361
	N	123	123	123	123	123	123	123
Households	Pearson Correlation	.310**	1	.208*	-.141	-.099	-.114	.052
	Sig. (2-tailed)	.000		.021	.119	.274	.211	.570
	N	123	123	123	123	123	123	123
EMPDEN	Pearson Correlation	-.281**	.208*	1	.097	.186*	-.061	.226*
	Sig. (2-tailed)	.002	.021		.285	.039	.506	.012
	N	123	123	123	123	123	123	123
LowSkilled	Pearson Correlation	-.071	-.141	.097	1	.888**	-.122	.502**
	Sig. (2-tailed)	.433	.119	.285		.000	.180	.000
	N	123	123	123	123	123	123	123
NoLowSkill	Pearson Correlation	-.082	-.099	.186*	.888**	1	-.131	.578**
	Sig. (2-tailed)	.370	.274	.039	.000		.147	.000
	N	123	123	123	123	123	123	123
UnempRate	Pearson Correlation	.165	-.114	-.061	-.122	-.131	1	-.163
	Sig. (2-tailed)	.067	.211	.506	.180	.147		.072
	N	123	123	123	123	123	123	123
NoBusLines	Pearson Correlation	-.083	.052	.226*	.502**	.578**	-.163	1
	Sig. (2-tailed)	.361	.570	.012	.000	.000	.072	
	N	123	123	123	123	123	123	123

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

APPENDIX B

Correlation model summary

(All Variables without Total Population and Acres)

Correlations

		Daily_On	Income	Vehicles	POPDEN	HUDEN	BlackRate	FemaleRate
Daily_On	Pearson Correlation	1	-.130	.026	-.002	-.031	-.090	-.065
	Sig. (2-tailed)		.151	.778	.985	.733	.325	.474
	N	123	123	123	123	123	123	123
Income	Pearson Correlation	-.130	1	.353**	-.238**	-.086	-.585**	-.215*
	Sig. (2-tailed)	.151		.000	.008	.346	.000	.017
	N	123	123	123	123	123	123	123
Vehicles	Pearson Correlation	.026	.353**	1	.111	.187*	-.521**	-.080
	Sig. (2-tailed)	.778	.000		.221	.039	.000	.379
	N	123	123	123	123	123	123	123
POPDEN	Pearson Correlation	-.002	-.238**	.111	1	.842**	-.212*	.077
	Sig. (2-tailed)	.985	.008	.221		.000	.018	.398
	N	123	123	123	123	123	123	123
HUDEN	Pearson Correlation	-.031	-.086	.187*	.842**	1	-.333**	-.008
	Sig. (2-tailed)	.733	.346	.039	.000		.000	.929
	N	123	123	123	123	123	123	123
BlackRate	Pearson Correlation	-.090	-.585**	-.521**	-.212*	-.333**	1	.244**
	Sig. (2-tailed)	.325	.000	.000	.018	.000		.007
	N	123	123	123	123	123	123	123
FemaleRate	Pearson Correlation	-.065	-.215*	-.080	.077	-.008	.244**	1
	Sig. (2-tailed)	.474	.017	.379	.398	.929	.007	
	N	123	123	123	123	123	123	123
LowEdu	Pearson Correlation	-.083	-.341**	.274**	-.084	-.202*	.458**	.217*

	Sig. (2-tailed)	.360	.000	.002	.353	.025	.000	.016
	N	123	123	123	123	123	123	123
Households	Pearson Correlation	-.052	.106	.719**	.289**	.490**	-.361**	.019
	Sig. (2-tailed)	.569	.245	.000	.001	.000	.000	.837
	N	123	123	123	123	123	123	123
EMPDEN	Pearson Correlation	.141	-.054	.138	.386**	.394**	-.351**	-.071
	Sig. (2-tailed)	.119	.552	.128	.000	.000	.000	.437
	N	123	123	123	123	123	123	123
LowSkilled	Pearson Correlation	.355**	-.065	.033	-.249**	-.233**	-.085	-.076
	Sig. (2-tailed)	.000	.474	.716	.006	.009	.349	.403
	N	123	123	123	123	123	123	123
UnempRate	Pearson Correlation	-.045	-.418**	-.234**	.210*	.067	.363**	.142
	Sig. (2-tailed)	.618	.000	.009	.019	.460	.000	.118
	N	123	123	123	123	123	123	123
NoBusLines	Pearson Correlation	.699**	.001	.210*	-.035	-.091	-.256**	-.090
	Sig. (2-tailed)	.000	.992	.020	.702	.316	.004	.325
	N	123	123	123	123	123	123	123

Correlations

		LowEdu	Households	EMPDEN	LowSkilled	UnempRate	NoBusLines
Daily_On	Pearson Correlation	-.083	-.052	.141	.355**	-.045	.699**
	Sig. (2-tailed)	.360	.569	.119	.000	.618	.000
	N	123	123	123	123	123	123
Income	Pearson Correlation	-.341**	.106	-.054	-.065	-.418**	.001
	Sig. (2-tailed)	.000	.245	.552	.474	.000	.992
	N	123	123	123	123	123	123
Vehicles	Pearson Correlation	.274**	.719**	.138	.033	-.234**	.210*
	Sig. (2-tailed)	.002	.000	.128	.716	.009	.020
	N	123	123	123	123	123	123
POPDEN	Pearson Correlation	-.084	.289**	.386**	-.249**	.210*	-.035
	Sig. (2-tailed)	.353	.001	.000	.006	.019	.702
	N	123	123	123	123	123	123
HUDEN	Pearson Correlation	-.202*	.490**	.394**	-.233**	.067	-.091
	Sig. (2-tailed)	.025	.000	.000	.009	.460	.316
	N	123	123	123	123	123	123
BlackRate	Pearson Correlation	.458**	-.361**	-.351**	-.085	.363**	-.256**
	Sig. (2-tailed)	.000	.000	.000	.349	.000	.004
	N	123	123	123	123	123	123

FemaleRate	Pearson Correlation	.217*	.019	-.071	-.076	.142	-.090
	Sig. (2-tailed)	.016	.837	.437	.403	.118	.325
	N	123	123	123	123	123	123
LowEdu	Pearson Correlation	1	.310**	-.281**	-.071	.165	-.083
	Sig. (2-tailed)		.000	.002	.433	.067	.361
	N	123	123	123	123	123	123
Households	Pearson Correlation	.310**	1	.208*	-.141	-.114	.052
	Sig. (2-tailed)	.000		.021	.119	.211	.570
	N	123	123	123	123	123	123
EMPDEN	Pearson Correlation	-.281**	.208*	1	.097	-.061	.226*
	Sig. (2-tailed)	.002	.021		.285	.506	.012
	N	123	123	123	123	123	123
LowSkilled	Pearson Correlation	-.071	-.141	.097	1	-.122	.502**
	Sig. (2-tailed)	.433	.119	.285		.180	.000
	N	123	123	123	123	123	123
UnempRate	Pearson Correlation	.165	-.114	-.061	-.122	1	-.163
	Sig. (2-tailed)	.067	.211	.506	.180		.072
	N	123	123	123	123	123	123
NoBusLines	Pearson Correlation	-.083	.052	.226*	.502**	-.163	1
	Sig. (2-tailed)	.361	.570	.012	.000	.072	
	N	123	123	123	123	123	123

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

APPENDIX C

Correlation model summary

(All Variables without Population Density, Household Density and Employment Density)

Correlations

		Daily_On	Income	Vehicles	BlackRate	FemaleRate	LowEdu	Households
Daily_On	Pearson Correlation	1	-.130	.026	-.090	-.065	-.083	-.052
	Sig. (2-tailed)		.151	.778	.325	.474	.360	.569
	N	123	123	123	123	123	123	123
Income	Pearson Correlation	-.130	1	.353**	-.585**	-.215*	-.341**	.106
	Sig. (2-tailed)	.151		.000	.000	.017	.000	.245
	N	123	123	123	123	123	123	123
Vehicles	Pearson Correlation	.026	.353**	1	-.521**	-.080	.274**	.719**
	Sig. (2-tailed)	.778	.000		.000	.379	.002	.000
	N	123	123	123	123	123	123	123
BlackRate	Pearson Correlation	-.090	-.585**	-.521**	1	.244**	.458**	-.361**
	Sig. (2-tailed)	.325	.000	.000		.007	.000	.000
	N	123	123	123	123	123	123	123
FemaleRate	Pearson Correlation	-.065	-.215*	-.080	.244**	1	.217*	.019
	Sig. (2-tailed)	.474	.017	.379	.007		.016	.837
	N	123	123	123	123	123	123	123
LowEdu	Pearson Correlation	-.083	-.341**	.274**	.458**	.217*	1	.310**
	Sig. (2-tailed)	.360	.000	.002	.000	.016		.000
	N	123	123	123	123	123	123	123
Households	Pearson Correlation	-.052	.106	.719**	-.361**	.019	.310**	1
	Sig. (2-tailed)	.569	.245	.000	.000	.837	.000	
	N	123	123	123	123	123	123	123
LowSkilled	Pearson Correlation	.355**	-.065	.033	-.085	-.076	-.071	-.141

	Sig. (2-tailed)	.000	.474	.716	.349	.403	.433	.119
	N	123	123	123	123	123	123	123
\UnempRate	Pearson Correlation	-.045	-.418**	-.234**	.363**	.142	.165	-.114
	Sig. (2-tailed)	.618	.000	.009	.000	.118	.067	.211
	N	123	123	123	123	123	123	123
NoBusLines	Pearson Correlation	.699**	.001	.210*	-.256**	-.090	-.083	.052
	Sig. (2-tailed)	.000	.992	.020	.004	.325	.361	.570
	N	123	123	123	123	123	123	123
TotalPop	Pearson Correlation	.070	-.079	.718**	-.197*	.128	.554**	.667**
	Sig. (2-tailed)	.439	.384	.000	.029	.160	.000	.000
	N	123	123	123	123	123	123	123
Acres	Pearson Correlation	.078	.141	.321**	-.032	-.055	.165	.133
	Sig. (2-tailed)	.388	.119	.000	.725	.543	.069	.142
	N	123	123	123	123	123	123	123

		LowSkilled	UnempRate	NoBusLines	TotalPop	Acres
Daily_On	Pearson Correlation	.355**	-.045	.699**	.070	.078
	Sig. (2-tailed)	.000	.618	.000	.439	.388
	N	123	123	123	123	123
Income	Pearson Correlation	-.065	-.418**	.001	-.079	.141
	Sig. (2-tailed)	.474	.000	.992	.384	.119
	N	123	123	123	123	123
Vehicles	Pearson Correlation	.033	-.234**	.210*	.718**	.321**
	Sig. (2-tailed)	.716	.009	.020	.000	.000
	N	123	123	123	123	123
BlackRate	Pearson Correlation	-.085	.363**	-.256**	-.197*	-.032
	Sig. (2-tailed)	.349	.000	.004	.029	.725
	N	123	123	123	123	123
FemaleRate	Pearson Correlation	-.076	.142	-.090	.128	-.055
	Sig. (2-tailed)	.403	.118	.325	.160	.543
	N	123	123	123	123	123
LowEdu	Pearson Correlation	-.071	.165	-.083	.554**	.165
	Sig. (2-tailed)	.433	.067	.361	.000	.069
	N	123	123	123	123	123
Households	Pearson Correlation	-.141	-.114	.052	.667**	.133
	Sig. (2-tailed)	.119	.211	.570	.000	.142
	N	123	123	123	123	123
LowSkilled	Pearson Correlation	1	-.122	.502**	-.019	.549**

	Sig. (2-tailed)		.180	.000	.838	.000
	N	123	123	123	123	123
UnempRate	Pearson Correlation	-.122	1	-.163	.057	-.117
	Sig. (2-tailed)	.180		.072	.534	.196
	N	123	123	123	123	123
NoBusLines	Pearson Correlation	.502**	-.163	1	.229*	.111
	Sig. (2-tailed)	.000	.072		.011	.222
	N	123	123	123	123	123
TotalPop	Pearson Correlation	-.019	.057	.229*	1	.189*
	Sig. (2-tailed)	.838	.534	.011		.037
	N	123	123	123	123	123
Acres	Pearson Correlation	.549**	-.117	.111	.189*	1
	Sig. (2-tailed)	.000	.196	.222	.037	
	N	123	123	123	123	123

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

APPENDIX D

THE DATA OF 161 BLOCK GROUPS

Table 13: Exact boarding number, model assessment and %error of each block group

GID	Income	NoBusLines	Daily_On	ModelAssessment	ExaNo-Assessment	%Error
517600102001	40441	9	324	54.721	269	492.0944
517600102002	80000	10	31	-25.549	57	-221.335
517600102003	35161	10	37	108.968	-72	-66.0451
517600102004	66458	10	21	15.077	6	39.285
517600103001	29050	11	92	165.708	-74	-44.4807
517600104011	59604	20	19	419.709	-401	-95.4731
517600104012	21983	12	251	225.316	26	11.3991
517600104021	101146	8	8	-165.801	174	-104.825
517600104022	40833	9	88	53.545	34	64.34774
517600104023	41131	9	140	52.651	87	165.9019
517600105001	38804	10	150	98.039	52	53.00034
517600105002	72560	10	56	-3.229	59	-1834.28
517600106001	61227	25	111	606.875	-496	-81.7096
517600107001	26563	6	30	-18.866	49	-259.016
517600107002	34375	9	36	72.919	-37	-50.6302
517600107003	27379	9	198	93.907	104	110.8469
517600108001	51587	9	172	21.283	151	708.1567
517600108002	25895	17	180	405.615	-226	-55.6229
517600108003	28500	7	182	13.73	168	1225.564
517600109001	31287	7	1	5.369	-4	-81.3746
517600109002	37740	8	249	24.417	225	919.7813
517600109003	33125	5	71	-76.959	148	-192.257
517600109004	27353	8	88	55.578	32	58.33603
517600110001	47961	2	10	-236.688	247	-104.225
517600110002	39671	9	126	57.031	69	120.9325
517600110003	27155	7	121	17.765	103	581.1146
517600111001	57132	3	36	-225.794	262	-115.944

517600111002	47250	11	103	111.108	-8	-7.2974
517600111003	17418	5	49	-29.838	79	-264.22
517600111004	33188	16	38	345.329	-307	-88.996
517600201001	13726	7	242	58.052	184	316.8676
517600202001	10365	15	439	375.391	64	16.94473
517600202002	15640	8	228	90.717	137	151.3311
517600203001	27961	10	128	130.568	-3	-1.96679
517600203002	23380	15	184	336.346	-152	-45.2944
517600204001	20417	2	8	-154.056	162	-105.193
517600204002	15000	4	14	-60.991	75	-122.954
517600204003	17012	9	187	125.008	62	49.59043
517600204004	14100	7	179	56.93	122	214.4212
517600204005	11607	7	36	64.409	-28	-44.1072
517600205001	15741	15	157	359.263	-202	-56.2994
517600205002	55496	33	507	931.324	-424	-45.5614
517600206001	69844	12	129	81.733	47	57.83099
517600206002	67969	12	103	87.358	16	17.90563
517600207001	22917	13	122	260.921	-139	-53.2426
517600208001	77303	15	121	174.577	-54	-30.6896
517600209001	36406	14	148	258.861	-111	-42.8265
517600209002	30400	13	14	238.472	-224	-94.1293
517600209003	32434	4	101	-113.293	214	-189.149
517600210001	16845	20	62	547.986	-486	-88.6858
517600210002	28400	8	16	52.437	-36	-69.4872
517600211001	35711	29	210	837.051	-627	-74.9119
517600212001	36295	11	67	143.973	-77	-53.4635
517600301001	9942	10	358	184.625	173	93.90657
517600301002	10962	4	83	-48.877	132	-269.814
517600302001	35848	23	2453	606.198	1847	304.6533
517600302002	-	19	3466	#VALUE!	#VALUE!	#VALUE!
517600305001	28167	72	5368	2511.184	2857	113.7637
517600305002	14846	20	372	553.983	-182	-32.8499
517600402001	19303	7	326	41.321	285	688.9451
517600402002	34083	47	432	1533.261	-1101	-71.8248
517600403001	15018	29	472	899.13	-427	-47.5048
517600404001	15000	9	409	131.044	278	212.1089
517600404002	18750	7	18	42.98	-25	-58.1201
517600405001	57449	4	215	-188.338	403	-214.156
517600405002	40500	11	471	131.358	340	258.5621
517600406001	39669	14	123	249.072	-126	-50.6167
517600407001	55030	17	175	318.21	-143	-45.0049
517600408001	48750	15	96	260.236	-164	-63.1104
517600409001	46383	6	27	-78.326	105	-134.471

517600409002	50690	11	49	100.788	-52	-51.3831
517600410001	98158	7	9	-195.244	204	-104.61
517600410002	59500	13	145	151.172	-6	-4.08277
517600411001	35893	7	13	-8.449	21	-253.864
517600411002	39187	7	41	-18.331	59	-323.665
517600411003	37132	14	115	256.683	-142	-55.1977
517600412001	41806	11	30	127.44	-97	-76.4595
517600413001	18650	23	348	657.792	-310	-47.0957
517600413002	36094	12	64	182.983	-119	-65.0241
517600414001	38088	13	32	215.408	-183	-85.1445
517600414002	39239	12	75	173.548	-99	-56.7843
517600416001	66845	5	18	-178.119	196	-110.106
517600416002	44455	9	20	42.679	-23	-53.1385
517600501001	48581	18	241	375.964	-135	-35.8981
517600501002	59583	14	27	189.33	-162	-85.7392
517600502001	73938	19	246	338.3	-92	-27.2835
517600502002	96020	10	12	-73.609	86	-116.302
517600502003	134970	8	5	-267.273	272	-101.871
517600503001	72250	21	41	420.178	-379	-90.2422
517600504001	95982	17	17	195.354	-178	-91.2978
517600504002	137153	22	46	263.876	-218	-82.5676
517600505001	56507	20	106	429	-323	-75.2914
517600505002	130714	19	30	167.972	-138	-82.1399
517600505003	-	6	41	#VALUE!	#VALUE!	#VALUE!
517600506001	194000	6	1	-521.177	522	-100.192
517600506002	221500	12	1	-373.235	374	-100.268
517600602001	38276	14	92	253.251	-161	-63.6724
517600602002	31250	7	109	5.48	104	1889.051
517600602003	41583	6	23	-63.926	87	-135.979
517600604001	19973	15	164	346.567	-183	-52.6787
517600604002	38988	7	57	-17.734	75	-421.416
517600604003	21528	3	61	-118.982	180	-151.268
517600604004	25547	13	135	253.031	-118	-46.6469
517600604005	30531	8	18	46.044	-28	-60.907
517600605001	39821	3	47	-173.861	221	-127.033
517600605002	59375	4	14	-194.116	208	-107.212
517600605003	63696	7	31	-91.858	123	-133.748
517600605004	52482	6	11	-96.623	108	-111.384
517600605005	30679	19	184	468.077	-284	-60.6902
517600606001	84688	9	125	-78.02	203	-260.215
517600606002	52813	9	31	17.605	13	76.08634
517600606003	86375	0	0	-428.744	429	-100
517600607001	21589	10	106	149.684	-44	-29.1841

517600607002	26989	10	200	133.484	67	49.83069
517600607003	13355	10	91	174.386	-83	-47.8169
517600607004	21161	8	29	74.154	-45	-60.8922
517600607005	21135	9	107	112.639	-6	-5.00626
517600608001	25789	6	94	-16.544	111	-668.182
517600608002	37083	23	201	602.493	-401	-66.6386
517600608003	26641	8	34	57.714	-24	-41.0888
517600609001	36438	19	109	450.8	-342	-75.8208
517600610001	20293	15	85	345.607	-261	-75.4056
517600610002	31671	50	835	1655.718	-821	-49.5687
517600701001	94850	3	13	-338.948	352	-103.835
517600701002	82026	2	2	-338.883	341	-100.59
517600701003	48375	20	71	453.396	-382	-84.3404
517600703001	46989	16	100	303.926	-204	-67.0973
517600703002	91620	0	0	-444.479	444	-100
517600704001	61685	7	53	-85.825	139	-161.754
517600704002	85938	9	42	-81.77	124	-151.364
517600704003	97434	0	0	-461.921	462	-100
517600706011	17692	17	119	430.224	-311	-72.34
517600706012	32083	6	35	-35.426	70	-198.797
517600706013	30987	4	57	-108.952	166	-152.317
517600706014	32870	8	11	39.027	-28	-71.8144
517600706021	44418	12	294	158.011	136	86.063
517600706022	48779	7	37	-47.107	84	-178.545
517600707001	48329	6	10	-84.164	94	-111.882
517600707002	35294	7	131	-6.652	138	-2069.33
517600708011	40583	10	27	92.702	-66	-70.8744
517600708012	38118	2	3	-207.159	210	-101.448
517600708013	61944	3	10	-240.23	250	-104.163
517600708014	36995	1	20	-242.197	262	-108.258
517600708021	35750	8	37	30.387	7	21.7626
517600708022	40046	6	37	-59.315	96	-162.379
517600708023	53068	4	0	-175.195	175	-100
517600709001	24148	1	50	-203.656	254	-124.551
517600709002	37292	5	111	-89.46	200	-224.078
517600709003	34438	9	27	72.73	-46	-62.8764
517600709004	35703	0	0	-276.728	277	-100
517600709005	59926	6	19	-118.955	138	-115.972
517600710011	55234	7	9	-66.472	75	-113.54
517600710012	35069	6	54	-44.384	98	-221.665
517600710013	34450	4	32	-119.341	151	-126.814
517600710014	43422	12	22	160.999	-139	-86.3353
517600710021	53105	6	11	-98.492	109	-111.168

517600710022	27500	22	77	592.835	-516	-87.0116
517600711001	67740	11	12	49.638	-38	-75.825
517600711002	30300	3	11	-145.298	156	-107.571
517600711003	42031	9	10	49.951	-40	-79.9804
517600711004	60901	10	7	31.748	-25	-77.9514

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