Investigating the Determining Factors for Transit Travel Demand by Bus Mode in US Metropolitan Statistical Areas

MTI Report 12-30

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REPORT 12-30

INVESTIGATING THE DETERMINING FACTORS FOR TRANSIT TRAVEL DEMAND BY BUS MODE IN US METROPOLITAN STATISTICAL AREAS

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16. Abstract

Proper understanding of the nature of the transit travel demand is at the heart of transportation policy making and the success of transit systems. Unfortunately, most of the existing studies have focused on a single or few transit systems or metropolitan areas to analyze the determinants of transit travel demand. This study is an attempt to investigate the determining factors for transit travel demand by bus mode in the United States at Metropolitan Statistical Areas in 2010. The multiple regression results indicate that seven internal factors, which the transit managers and operators have control over, and only one external variable, namely gas price, show to have significant impacts on transit travel demand by bus mode. Transit supply, transit fare, average headway, transit coverage, service intensity, revenue hours, and safety are the contributing internal factors for transit demand by bus. This indicates that the mechanisms to increase the transit ridership patronage are in the hands of the transit authorities, which further indicates that they do not need to depend on outside world to attract more ridership but can do so by adjusting the influential internal factors that are under their control.

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EXECUTIVE SUMMARY

This study is an attempt to investigate the factors determining transit travel demand by bus mode at US Metropolitan Statistical Areas in 2010. It examines the impacts of both internal and external factors on transit travel demand. Broadly, it analyzes the relationships among physical environment, socioeconomic environment, transit systems characteristics, and transit travel demand.

Although the demand for transit travel in the United States has historically been low, it is generally believed that factors such as gas price hikes over the last decade compelled many auto drivers to switch to using transit. It is important for transit policy makers, planners, managers, and operators to understand the explanatory factors for transit demand so they can create appropriate policies and take necessary actions to provide taxpayers with efficient transit systems. Hence, there is a need for a study that analyzes transit travel demand in recent years. This study attempts to do so by focusing on 2010.

The authors collected data on all 358 Metropolitan Statistical Areas (MSAs) in the US. However, the final regression model included 273 MSAs. A total of 85 MSAs were excluded due to missing values. The data for the study comes primarily from two sources: the Census Bureau (2010) and Integrated National Transit Database Analysis System (INTDAS 2012). The authors constructed a few variables as well. For instance, service intensity was constructed by dividing vehicle miles by route miles. Transit coverage is a constructed variable that measures the ratio of MSA population to route miles in the respective MSA. Similarly, transit fare was constructed as the ratio of fare revenue to passenger trips. The authors also constructed variables such as gas price, metropolitan sprawling index (MSI), and transit orientation pattern. While gas price was constructed from a public website (GasBuddy.com 2013), MSI was calculated based on the procedures shown by Ewing et al. (2003). Transit orientation pattern, a dichotomous variable, was estimated through a combination of surveys and visual inspection of the transit system networks. The authors used a wide array of variables in their initial models but dropped those that showed high collinearity with other explanatory variables.

Using an Ordinary Least-Squares (OLS) regression model, the study finds that internal factors were the predominant significant predictors of transit travel demand by bus mode in 2010. The R^2 value (coefficient of multiple determination) for the model is 0.907, which indicates that the independent variables selected for this study explain approximately 90 percent of the variability in the dependent variable, passenger miles per capita. The F statistic for the model is 130.034 with a significance level of 0.000, which shows that the model fit was good.

External factors are those that transit managers and operators cannot control. Unlike external factors, internal factors are system-specific and controllable by transit managers and operators. The results indicate that while seven out of eight internal variables were found to cause significant impacts on transit travel demand, only one external variable was significant predictor. The significant internal predictors are transit fare, transit supply, revenue hours, average headway, safety, transit coverage, and service intensity. Gas price is the sole external factor that emerged as a significant explanatory variable of transit travel demand by bus.

Since this is a comprehensive study that includes all MSAs in the country, its findings are significant. Since the predominant significant predictors of transit travel demand by bus mode are found to be internal, it is probably safe to argue that the managers and operators can control ridership without depending on outside factors. They can increase transit ridership by adjusting the quantity and quality of transit services they provide. Keeping this in mind, transit policy makers and planners can create plans and policies that provide taxpayers with efficient transit systems they naturally want to use.

I. INTRODUCTION

BACKGROUND

Transit has been the least demanded transportation mode in terms of number of trips in the US for last few decades (Alam 2009). Its demand, as a percentage of total trips made by all travel modes, has been essentially stable since 1970, despite various government initiatives to increase patronage. Such initiatives include increasing subsidies for transit systems and maintaining relatively low fares (Taylor et al. 2009). National Household Travel Survey (NHTS) data for the US indicates that in 2001 the share of total trips by private vehicle, on foot or bicycle, and by other modes, were 85.8 percent, 9.9 percent, and 2.2 percent, respectively, while transit's contribution was only 2.1 percent (NHTS 2001). Despite its minuscule market share, transit patronage increased by approximately 7 percent between 1990 and 2000 (Pucher 2002). As presented in Figure 1, transit ridership by bus was at a low level during the Great Depression in the early 1930s. Demand increased rapidly starting in 1934 and reached its peak in 1948. Since then, bus transit ridership declined steadily until 1972 and has been relatively stable since then, with unlinked passenger trips varying between 5,000 million and 6,000 million per year.
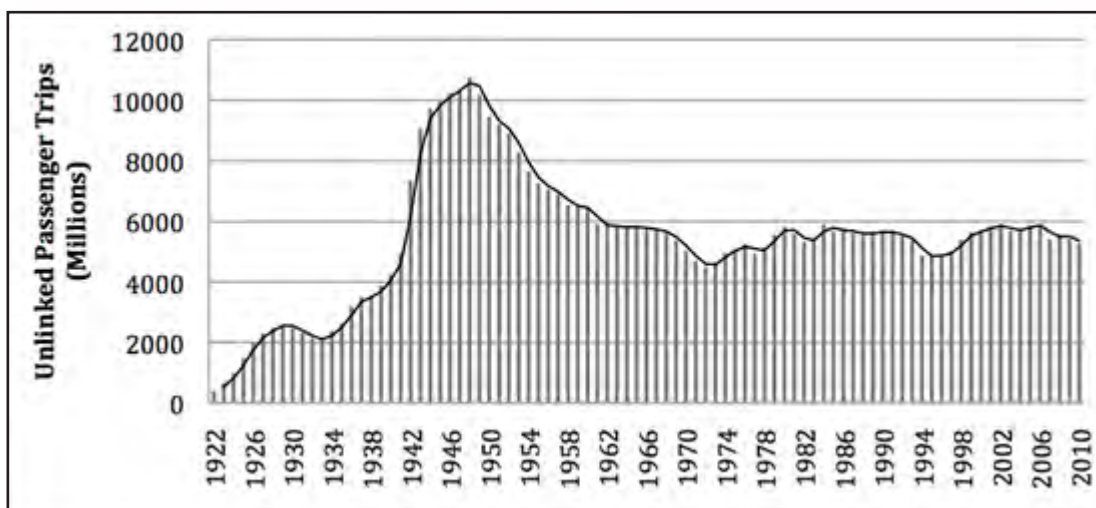
Figure 1.   Annual Transit Ridership Trend by Bus, 1922 to 2010

Data Source: American Public Transportation Association 2012. Public Transportation Fact Book, Appendix A: Historical Tables.

Proper understanding of the nature of the transit travel demand model lies at the heart of transportation policy making and the success of transit systems. Unfortunately, most of the existing studies have focused on the determinants of transit travel demand in a single or just a few transit systems (Thompson and Brown 2006). Due to the geographic uniqueness of each study's unit of analysis, it is difficult to arrive at a general conclusion and recommendation from these studies. Questions arise: What are the significant determinants of transit ridership demand, and why are they important for policy makers, transit managers, and transit users? To what degree is travel demand impacted by environmental factors related to geographic units (e.g. MSA size, transit orientation pattern), which are external to the transit system and typically beyond the control of transit

managers and operators? Are these factors more or less significant than internal, system-specific factors, over which transit managers and operators have some control? Did the increase in gas prices during the economic downturn over the last decade have an impact on transit travel demand? Does the demand for transit travel correspond in any way to the metropolitan sprawling index (MSI), a composite measure of several dimensions of Metropolitan Statistical Areas' (MSA) physical orientation? Does an increase in college population and carless households affect on transit demand? This study seeks to answer such questions using the data on bus-only mode for 2010. The presence of rail transit in an MSA may impact the demand for bus transit. Some riders may use a bus as a transit mode at the beginning and/or end of a rail transit trip. Others may avoid bus transit and use only rail, or vice versa. Therefore, this study also attempts to determine whether the presence of rail transit in an MSA significantly impacts the demand for transit by bus.

RATIONALE AND OBJECTIVE OF THE STUDY

Over the past few decades, several studies have explored factors that affect transit travel demand. Some have focused on a single factor in multiple geographic units, ignoring the influence of other factors. These variables usually relate to gasoline prices (Lane 2010; Lane 2012), local transit policies (Thompson 1977; Litman 2004), urban development form (Neog 2009), or accessibility to automobiles (Sanchez 1999). Other studies have looked at the effects of multiple factors (e.g., population, employment, gasoline price, transit fare, service quality, vehicle revenue hours, vehicle miles traveled, and/or percentage of carless households) in a single geographic unit, ignoring the external validity of the outcomes (Chen et al. 2011; Thompson and Brown 2012a; Gutierrez et al. 2011; Brown and Thompson 2008a; Gomez-Ibanez 1996; Cervero 1982). These studies generally conclude that higher gasoline prices have small but statistically significant effects on transit ridership (Chen et al. 2011; Lane 2012). However, findings for the other factors mentioned above are inconclusive. Since these studies are conducted on single geographic unit, it is difficult to draw general conclusions about the determining factors of transit demand at the national level. Lack of general theoretical guidelines, inconsistency in regression models and methodologies, and differences in geographic scales of the previous studies yield inconclusive results. Hence, there is a need to examine transit travel demand functions that include both geographic-unit-related variables and transit system-specific variables at the national level.

Although the market share of transit is very low, typical transit users in small and mid-sized MSAs are the most disadvantaged groups of our society: people with disabilities, elderly and poor populations, and women (Alam 2009). To serve these groups, it is important to plan prudently and distribute available resources wisely; thus, it is essential for the transit planners and policy makers to properly understand transit travel demand functions. The goal of this study is to increase that understanding by comprehensively identifying the factors that determined demand for bus transit in US MSAs in 2010.

LIMITATIONS OF THE STUDY

Initially, the authors envisioned conducting a comparative cross-sectional study of two timeframes: 2000 and 2010. Unfortunately, the 2000 database lacked data on transit fare, a very important explanatory variable identified by earlier studies (Taylor et al. 2009). In addition, the Office of Management and Budget (OMB) realigned a few MSA boundaries between 2000 to 2010 due to significant changes in demographic and socioeconomic factors in these MSAs, creating a lack of uniformity among the MSA boundaries between 2000 and 2010. This meant the authors could not use panel data to compare identical determining factors in the two time periods as was their original intent. They therefore decided to focus only on the year 2010 in seeking answers to the questions discussed earlier.

II. LITERATURE REVIEW

This literature review surveys and synthesizes research literature concerning determinants of transit travel demand produced over the last 10 to 15 years. Its purpose is to explore the theoretical context under which different factors influence transit travel demand. The review presents a comprehensive overview of recent empirical research regarding internal and external determinants of transit travel demand at different geographical scales. It begins with a discussion of debate over transit analysis areas; next considers research methodology; then debates transit ridership factors, focusing on external factors—land use, fuel price, socioeconomic factors, and access to transit; and then provides an overview of internal factors, including transit fare pricing, transit service coverage, average headway, transit service intensity, and transit orientation pattern. Finally, it provides concluding remarks on the reviewed literature.

DEBATE OVER TRANSIT ANALYSIS AREAS

Single-City vs. Multicity Studies

The debate over transit analysis areas remains serious because each geographical scale has its own pros and cons. Different studies have chosen different scales of study areas based on the objectives of the research. These study areas could be categorized into three groups: single city, multiple cities (multicity), and the nation.

The first category of literature focuses on transit demand in a single city or transit agency operated by one transit authority (Alam et al. 2010; Chen et al. 2011; Thompson and Brown 2012a; Gutierrez et al. 2011; Brown and Thompson 2008a; Gomez-Ibanez 1996; Cervero 1982; Sohn et al. 2012; Ballou and Mohan 1981). By concentrating on one transit agency, the studies can focus more deeply on specific issues. The analysis is more accurate and the solutions more effective because they are designed for a particular city. Ballou and Mohan (1981) proposed a transit pricing decision model to evaluate transit fare policies and to forecast travel demand by applying the microsimulation modeling technique to the Greater Albany, New York area, where public transportation was operated by only one agency: Capital District Transportation Authority. Similarly, Doti and Adibi (1991) developed a model to explain and forecast public transit ridership in Orange County, California. Gutierrez et al. (2011) developed a rapid response model to forecast transit ridership at the station level. In order to obtain a better estimation of the number of passengers entering the stations, the study focuses on the Madrid Metro network operated by one transit authority. They used the relationship between the distance to the station and the number of passengers entering the station as a weight for the explanatory variables in multiple regression models. The limitations of single-city studies are that they are narrowly focused on single study areas, and the solutions suggested by such studies cannot be directly transferred and generalized to other cities or regions.

To overcome the problem of external validity attached to single-city studies, i.e., the inability to generalize from limited case study data, some researchers use variables from multiple regions or transit systems (Thompson and Brown 2012b; TCRP No. 4 1995; TCRP No. 29 1998; Cervero 2006a; Sanchez 1999; Thompson and Matoff 2003; Demery 1994; Crane

2008; Taylor et al. 2002; Neog 2009; Lane 2010; Currie and Wallis 2008). The findings of such studies are considered applicable to other study areas. For example, Brown and Thompson (2012) studied the relative effect of two types of policies that were intended to increase the ridership and productivity of public transit service in Broward County and Tarrant County in Florida. The transit system in Tarrant County is a central business district (CBD) oriented in a radial pattern. It was designed to improve transit effectiveness by centering service in the central city areas. Contrarily, the transit system in Broward County, adopted a multidestinational grid pattern. Its goal was to connect employment centers and population hubs as directly as possible. After comparing multiple external and internal variables, such as population, service productivity, efficiency, and monthly boarding, the authors argue that the Broward County transit service is more efficient and they suggest that transit systems seeking to increase ridership need to restructure routes to directly connect more destinations.

National Studies

Studies with UZAs as Units of Analysis

An UZA is defined as a region with higher population density and diverse socioeconomic features in comparison to areas surrounding it. One of the advantages of using UZAs is that they have clear boundaries. Taylor et al. (2009) uses 265 UZAs as geographical units of analysis for three reasons: 1) people live, work, and travel in UZAs instead of in transit operator service areas; 2) most large UZAs are served by more than one transit system with overlapped boundaries, hence, the use of UZAs as geographic units of analysis avoids the chaos of individual boundaries; and 3) federal subsidies are calculated based on UZAs instead of transit service areas. The problem with using this geographic unit is that transit system service area boundaries generally differ from UZA boundaries. It is not unusual for a single UZA to be served by two transit systems, making it difficult to evaluate the performance of each transit authority separately.

Studies with MSAs as Units of Analysis

Unlike UZAs, MSAs are geographic units with relative boundaries that encompass the substantial influential regions surrounding a core large city. While transit service area boundaries may not exactly match the MSA boundaries, they fall closely within MSA boundaries since transit is specifically designed to serve metropolitan transportation needs. To generalize their findings, several studies used MSAs as the geographic units of analysis (Thompson and Brown 2006; Thompson et al. 2006; Brown and Neog 2008; Lane 2012). Thompson and Brown (2006) first used MSAs at the national scale to study transit ridership change between 1990 and 2000. Brown and Neog (2008) used the same geographic units of analysis—all US MSAs that had more than 500,000 people in 1990 and 2000—to examine the relationship between the strength of the CBD and transit ridership. However, there are MSAs that have more than one transit agency working within their boundaries; therefore, the superiority of one over the other cannot be accurately determined. The appropriate unit of analysis depends on the nature of the study, the availability of suitable data, and the authors' perspectives.

DEBATE OVER RESEARCH METHODOLOGY

Descriptive Approach

The descriptive approach usually focuses on variables that cannot be precisely measured by numbers, such as attitudes and perceptions. This approach is also used to analyze and present other transit-related variables (Crane 2008; Brown and Thompson 2012; Brown and Thompson 2008b; Thompson 1977; Thompson et al. 2006; Walker 2008; Gomez-Ibanez 1996; Cervero 1982; Zito and Salvo 2011; Demery 1994; Sohn et al. 2012). Surveys and interviews are the most common methods used to collect such data, while descriptive measures such as tables, figures, maps, and central tendency are used to present them (Wachs 1976; TCRP No. 4 1995; TCRP No. 29 1998; TCRP NO. 16 1996; Currie and Wallis 2008; Taylor et al. 2002; Forkenbrock et al. 2001). For example, Thompson et al. (2006) calculated the percentage change in the MSA population since 1990, the percentage change in vehicle miles per capita since 1990, the percentage change in passenger miles per capita since 1990, and the percentage change in passenger miles per vehicle mile between 1990 and 2000. They investigated these factors in different MSA population groups. Demery (1994) tested the accuracy of ridership forecasts of six federally-funded projects from the supply-side analysis. The author tabulated the differences of observed transit systems from the perspective of maximum service level, maximum utilized capacity or vehicle occupancy, and the share of weekday ridership during the peak hour. The results indicate that the differences between the estimated number and the actual number were significant. It appears that the weaknesses of descriptive approach come from high subjectivity, biases based on limited information, and poor data collection.

Causal Approach

Causal approach is used to identify the cause-effect relationships between independent variables and a dependent variable. Generally, multivariate regression is used to distinguish the degree of influence for different internal and external variables (Kohn 2000; Doti and Adibi 1991; Gutierrez et al. 2011; Sanchez 1999; Thompson and Brown 2012a; Thompson et al. 2006; Taylor et al. 2009; Neog 2009; Lane 2010). For instance, Thompson and Brown (2006) developed multivariate regression models to explain cause-effect relationships between multiple factors and the percent change in passenger miles per capita. Similarly, Brown and Neog (2008) used a multivariate analysis to draw the conclusion that transit ridership was not tied to the strength of the CBD while taking into account the influence of internal and external factors.

Besides the multivariate regression models, the other popular causal analysis model uses time-series data (Brown and Thompson 2008a; Thompson and Matoff 2003; Chen et al. 2011; Lane 2012). Thompson and Matoff (2003) evaluated the radial transit approach and multidestinational transit approach in nine urban regions with an examination of such transit performance indicators as service supply, ridership, service effectiveness, efficiency of investments, and equity. The data were collected annually from 1983 to 1998. The study divided the nine transit systems into four categories based on regional transit orientation and regional structure, and then used a time-series model to analyze each category. The study found that while systems with a multidestinational approach carry a smaller share of

travel than radial systems, their overall regional performance is superior to the traditional radial systems.

DEBATE OVER TRANSIT RIDERSHIP FACTORS

Studies of public transit ridership analyze a range of economic, social, transit system, and other factors in order to identify significant determinants of ridership and transit mode share. The following literature examines the relative influence of internal (factors within the control of transit systems) and external factors (economic and demographic, for example), the interaction between those factors, and the role of public policy in supporting travel modes.

Several recent analyses of trends in US transit ridership find grounds for optimism regarding expanding use of public transit. Employing survey and statistical data from the early 1990s to 2004, Polzin and Chu (2005) found that the total number (but not the overall percentage share) of trips taken by public transit had increased and the overall mode share had stabilized, with some sporadic fluctuations associated with economic ups and downs. Litman (2006) found that developing demographic and economic trends (including the long-term rising price of gasoline) were eroding conditions that had supported the ascendance of the automobile. In a synthesis of recent data and literature, Millar (2012) found that demographic, environmental, and economic trends bode well for expansion of public transit travel mode share. For both Litman (2006) and Millar (2012), improvement in transit's share of travel is contingent on implementing coordinated public policy that takes advantage of projected trends.

International comparative studies of transit systems juxtapose and analyze transit data to identify reasons for differences in performance metrics such as travel mode share in different countries. One of the most important distinctions appears to be the role of public policy in supporting transit or automobile use. A 1996 study of transit use in selected US and Canadian cities (1970 –1995) found automobile use in Canada to be lower and transit ridership two times higher than in the US. Lower vehicle use in Canada was primarily associated with higher fuel prices, greater residential density in cities, and transportation, land use and urban development policies dating from the 1970s that regulated automobiles and supported transit use (Schimeck 1996).

Policy differences were also significant in two recent studies that compared travel mode share in Germany and the US. Although the higher fuel prices in Germany may play important role, Buehler (2011) found that Germans were four to five times more likely to walk, cycle, or ride transit than the Americans in any social group and in any demographic category, even after controlling for differences in socioeconomic and land use factors. This finding is important because these two countries exhibit comparable levels of auto ownership and infrastructure development. Using highly comparable travel data for the US and Germany, while focusing on differences in transit systems and policies, Buehler and Pucher (2012) found an integrated range of policy-supported transit service and land use factors in Germany to be a likely explanation for the relative success of German public transit.

External determinants of transit ridership are economic, sociodemographic, and other factors beyond the control of transit system planners and managers. Most research

identifies external determinants as the most significant influences on travel mode choice in the US, particularly within the wider context of long-term policy support for automobile use. Several recent studies found strong correlations between ridership, income and employment, real GDP, and other economic factors (Taylor et al. 2002; Yoh et al. 2003; Taylor et al. 2009). In a critical review and synthesis analysis of research literature, Taylor and Fink found that economic factors, such as employment, income, and auto ownership, furnished the best immediate explanations for changes in transit mode shares within the wider context of policy (federal to municipal) that has consistently supported automobile as the dominant mode of travel in the United States (Taylor and Fink 2003).

Studies of internal determinants assess the effect of service decisions made by transit agencies on ridership. Such studies generally conclude that transit's success is contingent on particular configurations of the built environment. Proponents of system determinants argue for transit systems' capacity to increase ridership through system design, fare adjustment, and service quality. Many studies compare the relative influence of fare and service (e.g., coverage and quality) on ridership. Armbruster (2012) found reduction in miles covered by transit had a greater negative effect on ridership than a significant fare increase. Other research found that positive incentives, such as system expansion, service improvement, and stable fares, best explained the success of certain transit systems (Kain and Liu 1999; Pucher 2002), which indicates that quality of service may be more important than fare.

External Factors

A large body of transportation research literature focuses on the relationship between urban land use and transit ridership. Most studies find some degree of empirical support for the association of population and employment density with viable public transportation systems. A subfield of studies examines the theory that travelers' mode choice may be influenced and transits' share of travel increased through investment in transit oriented development (TOD), which situates planned, or pre-existing, sites of residential and employment density adjacent to transit, usually rail service. A dissenting body of work argues that many urban areas are best served by cheap, flexible bus transportation systems that connect transit-dependent riders with dispersed employment sites (Alam 2009).

Urban Density

A number of recent studies examine relationships between land use, urban density, and travel mode choice on a scale intended to be large enough to enable generalization, yet grounded in empirical specificity. A comparative study of automobile dependency in 46 international cities, of which 13 are in the United States, found auto dependency to be most acute in the US, where it was associated with extremes in low-density, auto-centric land-use patterns, consistent with findings for other studies (Kenworthy 1999). Two studies found positive association between ridership, urban density, and transit accessibility. Kuby (2004) compared results for nine similar cities in disparate regions of the US, while Chakraborty (2013) correlated travel mode with land-use type, and socioeconomic and other variables throughout the state of Maryland. Guerra and Cervero (2011) modeled the influence of job and population density on transit ridership and operating costs for 23

rail transit systems in 10 US cities, finding that urban density increased the capital costs of transit but also made systems more cost effective through increased ridership. While these studies demonstrate an association between low-density land use and automobile travel on the one hand, and urban density and viable transit on the other, critics point out that claims for causal relationships are complicated by collinearity with other factors, such as differential access to autos in suburban and central city areas.

Literatures that focus on studies of land use and transit ridership have identified problems with various aspects of research. After first identifying four propositions as the foundation of arguments for transit oriented "smart growth," Handy (2005) found that none of the propositions was fully supported by the relevant research literature. Another review, a meta-analysis of research concerned with travel and the built environment, found that population and job densities were only weakly associated with travel behavior after controlling for a range of socioeconomic and other variables. The study also found that the disparate methodologies and/or small sample sizes of many studies limited their potential for comparison or synthesis with findings of other, more robust research (Ewing and Cervero 2010). Similarly, Taylor and Fink (2003) and Grengs (2001) cautioned that findings of causal associations between increasing ridership, land use, and urban design were complicated by high levels of collinearity among spatial variables (such as the coincidence of low population density with free parking), as well as between spatial and socioeconomic variables (e.g., high population density and low-income households).

Transit Oriented Development

Advocates of Transit Oriented Development (TOD) argue that compact, mixed-use residential density connected by "high-quality" (generally rail) transit service to employment clusters can provide a marketable urban alternative to travel by automobile. The appeal of TOD to planners is likely connected to their sense of being in control of factors thought to influence transit mode choice behavior, but researchers are mindful that the growth potential of TOD may be limited in practice to a self-selecting preference group.

Evidence for TOD's efficacy in influencing travel behavior appears to be equivocal. A 1997 study (Cervero and Kockelman) examined how "density, diversity, and design" of the built environment in the San Francisco Bay Area affected the mode choice of residents. Although the study found only modest elasticities between particular attributes of the built environment and changes in travel mode choice, the authors argued that the combined effect of TOD elements would exceed the sum of the parts. Similarly, Hendricks et al. (2005) found that residential density and reliable transit alone were not likely to convert regular drivers to public transportation use; additional factors such as disincentives for auto use and the intrinsic appeal of residences and lifestyle must augment the appeal of TOD. A 2004 study that assembled extensive data on TOD investments in five California metropolitan areas over a decade found solvency, but no concrete evidence of growth in transit ridership (Lund et al. 2004). Cervero argues that residential self-selection can be an expansive, rather than limiting, factor if TOD is buttressed by policies that reduce a) support for car commuters (e.g., parking), and b) barriers (e.g., mortgage policy) to residential mobility (Cervero 2007).

Some research has sought to determine whether property values in TOD areas might be indicators or proxies for hidden demand. Here, too, findings appear to be complicated by problems of collinearity. Although an initial spatial analysis indicated property values rose steadily with increasing proximity to a light rail line, Hess and Almeida (2007) found that high-income real estate received an inordinate benefit from proximity to transit in Buffalo, NY. A study of smart growth in San Diego found that TOD condominiums in pedestrian-oriented downtown environments appeared to be appreciating in value compared to those in more auto-centric environments, raising questions regarding the relative influence of living adjacent to transit versus other factors (Duncan 2011).

Several studies examine the linkage of transit use and residential density in specific urban areas, or the relative importance of residential and destination density. Examining smart growth policies in Portland, Oregon, Jun (2008) found a strong association between the reduction of solo car trips and mixed land use, extensive transit coverage, and limited highway access, but no evidence for the influence of TOD and compact development. Lindsey (2010) found that existing density in areas of Chicago supported a relatively high percentage of transit work trips, with potential for expansion without change in land use policy. Two studies found destination factors (e.g., transit proximity and area amenities) in the TOD equation to be more of a significant influence on transit use than residential density (Cervero 2006b; Chen et al. 2008). Overall, research on the relationship between density and transit use in origins and destinations appears to be complicated by the narrow focus of studies, the range of dissimilar urban environments, and difficulty in characterizing causal effects on ridership without household or survey-level data.

A number of studies of land use and travel mode choice cite policy-supported disincentives to auto use as an important factor in altering travel behavior. According to Taylor and Fink (2003), regulating the price and availability of parking may be the most effective tool available to inhibit solo auto use and support use of transit. But because discouraging auto use is a politically fraught policy goal in the US, urban planners apply the device sparingly. Several recent studies examine the use of parking regulations as a means of limiting auto traffic in congested urban areas. Finding that disincentivizing auto use with metered parking was too unpopular to implement citywide in Portland, Oregon, Duecker et al. (1998) recommended the use of integrated strategies to achieve transportation objectives in specific localities. A survey-based study of travel behavior that examined the effects of metered parking and transit incentives on auto congestion in a Portland commercial district found both a significant reduction in car commutes and an increase in transit trips to the area (Bianco 2000). Similarly, Cervero (2007) found that discontinuation of employer support (such as cheap parking) for car commuting helped facilitate the appeal of transit-adjacent residential development in California.

Strength of the CBD

Due to a strong historic and contemporary association of urban density with effective public transit systems, the two may appear to be necessarily connected. A dissenting body of literature questions whether that association is applicable to American cities characterized by 20th century sprawl. A 2006 study challenged the prevailing assumption that transit system growth is linked to the vitality of "older urban forms" defined by central business

districts (CBDs) or analogous planned density (Thompson and Brown 2006). Examining growth in transit use in US metropolitan service areas between 1990 and 2000, the study found that transit ridership grew most rapidly in the West, where bus systems had adapted to patterns of dispersed residence and employment. Controlling for factors thought to influence ridership, a 2008 study found no relationship between the strength of CBDs and ridership increase for the same set of metropolitan areas (Brown and Neog 2008).

These and other related studies have been criticized for methodological limitations— for one, population parameters exclude MSAs with populations under 500 thousand or over 5 million (Thompson and Brown 2006)—that restrict the potential for generalizing from results. However, they offer a useful counterpoint to the tendency to apply a single model (CBD or analogous density) to improving transit service and increasing ridership in socially, economically, and geographically variant metropolitan areas. Also, their focus on using transit to connect groups lacking auto access to employment and other necessities may be more practical than attempts to influence travel mode choice with planned density.

Gasoline Price

Rising gasoline price may place budgetary constraints on auto use, particularly for middle-to-low-income drivers. Until recently, this situation had seldom seemed to apply to the United States, where low and relatively stable fuel prices have been the policy-supported norm. Since US fuel prices have become increasingly unstable over the last decade, researchers have revisited the cost of gasoline as a variable in transit mode choice.

Recent studies generally show a small but significant relation between rising fuel cost and increased ridership. A comparative study using international data found the aggregate of transit modes increase in ridership associated with fuel costs in the US to be modest (0.12 of a percent), consistent with the relatively low price of gasoline. In Australia, a nation with both comparable rates of auto dependency and higher fuel prices, the study found a more striking increase in transit ridership of 2.2 percent for every 10% increase in gasoline price (Currie and Phung 2007). A follow-up study comparing data from Australia and the US found that when home loan interest payments were added to the price of fuel in Australia, light rail ridership rose with the extra burden on income. The authors suggest that using a similar methodology, studies might shed light on comparable findings in the US (Currie and Phung 2008).

Studies of fuel cost and ridership in the US use selected cities, states, and regions to model and estimate national effects. A study based on time-series analyses of fuel prices and ridership for multimodal transit systems in five major US cities found statistically significant correlations between higher fuel cost and increased ridership for all but three (one rail and two bus) systems (Haire and Machemehl 2007). An analysis of public transit (rail and bus) ridership and fuel prices for nine major US cities from 2002 to 2008 similarly found a small but significant increase in ridership associated with changes in gas price (Lane 2010).

On a state or regional scale, several studies found modest increases in ridership related to rising fuel cost. Two studies—of urban bus systems in the Upper Midwest and Mountain Region (Mattson 2009) and of county transit systems in the state of Washington (Stover

and Bae 2011)—found gas prices associated with significant increase in ridership, with the elasticities of 0.12 and 0.17, respectively. Studies of New Jersey commuter transit similarly found small increases in ridership following fuel cost hikes over the last decade (Yanmaz-Tuzel and Ozbay 2010; Chen et al. 2011).

Finally, a study of Philadelphia metro area transit compared the effect of fuel cost increases on regional rail and city transit. It found the impact of gas price to be more highly correlated with commuter rail than with city transit, a result consistent with other studies that suggest rail ridership may be periodically bolstered by middle-income auto commuters pinched by gas (and other) price spikes, while city bus systems with transit-dependent patrons show little change (Maley and Weinberger 2009). On the whole, studies consistently reported discernible but impermanent increases in transit ridership that were roughly synchronous with significant hikes in fuel prices.

Socioeconomic Factors

Studies of socioeconomic determinants of transit ridership generally focus on the travel needs and behavior of demographic groups with very limited access to automobiles. Research shows that low-income groups lacking access to automobiles are most likely to rely on transit for access to employment and fulfillment of household and other necessities (Alam 2009; Holtzclaw et al. 2002; Polzin et al. 2000). A study based on the 2001 National Household Travel Survey found that even at the lowest income level, only 5% of trips were made using public transportation. Those most likely to use transit—the poor, racial and ethnic minorities, and the elderly—constituted 63 percent of the national transit ridership (Pucher and Renne 2003; Renne 2009). Giuliano (2005) found that regular transit users not only had the lowest level of mobility but also were most dissatisfied with existing service. Noting that serving transit-dependent riders is often a primary justification for funding transit systems, the study recommended improving service to retain existing riders' patronage.

A number of studies have focused on inequity in funding for transit modes (usually bus systems) that serve low-income demographic groups. A 1999 review of national data and related research found that although transit-dependent riders were the more reliable of two remaining transit constituencies (suburb-to-downtown commuters being the other), policy often focused—with only marginal success—on funding efforts to recapture lost suburban ridership (Garrett and Taylor 1999). Measuring subsidies for individual transit trips in Los Angeles, Iseki and Taylor (2001) found spending to be regressive with respect to income for underprivileged groups including African Americans, Latinos, youth, and women. Although most research indicates that groups with limited mobility are the mainstay of transit ridership, planners and system managers may resent being identified as social service providers. A recent study employing attitudinal survey data found that transit system managers emphasized urban environmental and design goals in their work, indicating tensions exist between planners' interests, public investment, and the demographic realities of ridership (Taylor and Breiland 2011).

In transportation research dating from the 1960s, "spatial mismatch" has generally referred to using public transportation to connect low-income, central-city job seekers to employment in suburban locations (Kain 1968). More recently, researchers have used technical innovations,

such as geographic information systems (GIS), to align household or Census tract-level socioeconomic data with street maps and transit system coverage, allowing more precise mapping of sociodemographic, employment, and transit access data (Sanchez 1999; Alam 2009). Graphic coordination of these factors enables visual representation and awareness of demographic groups whose travel needs are poorly served by public transit. Blumenberg and Shiki (2003) found that the central city/suburb model poorly represented the distribution of welfare recipients in medium-size cities and outlying rural areas, while Blumenberg (2004) found the "mismatch" model oblivious to the residential options, employment, and household travel needs of low-income single mothers.

Large numbers of recent immigrants have become public transit users since the mid-1990s, prompting research into their impact on transit systems and ridership. One study of transit use in California found that low-income, foreign-born riders comprise nearly 50 percent of transit commuters, a vital component of overall ridership (Blumenberg and Evans 2007). Related research indicated that many immigrants (varying by ethnicity) acculturate to auto ownership after five years, creating challenges for transit planners concerned with sustaining transit systems over time (Blumenberg and Shiki 2007). Studies of immigrant communities in "gateway" cities found low-income Latino immigrants most likely to use transit, with many also commuting by carpool (Donahue and Rodier 2008; Liu and Painter 2011). Analysis of nationwide data has found the foreign-born more likely to use transit but has also indicated, again, that use tends to decrease over time, indicating the necessity for planning and policy initiatives, such as service extension and outreach to communities, in order to sustain or increase ridership levels (Chatman and Klein 2009; Blumenberg 2009; Blumenberg and Evans 2010).

Access to Transit

Studies of accessibility examine the practical utility of public transit modes relative to automobiles in connecting job seekers to employment, providing acceptable walking distances to a transit stop, meeting affordability standards and providing adequate geographical coverage. Some research suggests that while transit can effectively link central-city job seekers to employment in dense CBD environments, automobile cost assistance may be more effective than bus transit in connecting low-income job seekers with dispersed suburban employment sites (Shen 2001; Hess 2005). Cervero et al. (2002) measured the relative success of welfare recipients from urban Alameda County (Oakland/East Bay Area) in obtaining employment via automobile or public transit. Automobility and education were found to be highly correlated with employment success, while transit had a negligible effect. Sanchez et al. (2004) found no consistent association between welfare (TANF) recipients' employment and access to transit in six selected metropolitan areas. Others, however, found a significant inverse impact between accessibility to jobs by transit and the length of time recipients are on welfare—that is, where jobs are more accessible by transit, recipients spend less time on the welfare (Alam 2005; Alam 2009; Alam, Thompson, and Brown 2010).

A comparative study highlighted the difficulties imposed by urban sprawl and flawed public transit for job seekers in Los Angeles and Boston who do not own cars, contrasting their limited success with better outcomes for job seekers in densely populated, transit-rich

Tokyo (Shen 2006). But Kawabata (2003) found that transit-based job accessibility (where it existed) was associated with improved chances of employment and working 30 hours or more per week for low-skilled, transit-dependent workers in Boston, San Francisco, and Los Angeles.

Other studies define accessibility in terms of spatial and temporal aspects of travel to work. Based on a survey of San Francisco Bay Area commuters, research utilizing ordinary least squares (OLS) and spatial regression models found that while greater accessibility to job destinations was associated with shorter commuting time for both automobile and transit users, the degree of association was much greater for transit (Kawabata and Shen 2007). In a study of access that counterposed two related factors – speed and density, rail transit in dense urban areas trumped the apparent speed of travel by auto through low-density built environments when access was measured in terms of a trip's starting and ending points' proximities to residence and workplace (Levine et al. 2012). Dill (2003) also found a strong association between transit use and proximity to work in the San Francisco Bay Area. In both studies, transit was seen to offer better access than cars under certain conditions.

A number of studies attempted to arrive at empirical, generalizable parameters for acceptable pedestrian access to transit by examining how far potential or transit-dependent riders were willing to walk to a transit stop (Hess 2009, Polzin et al. 2007, Dill 2003). The generally tolerable threshold for access was found to be a quarter mile or less, with use falling steadily beyond that distance.

Internal Factors

Internal determinants of transit ridership are factors within the control of system operators, including fare adjustments and a range of service factors. Transit fare increases and reductions are generally assumed to have a measurable impact on ridership. Studies have sought to determine the effect of positive (reductions) or negative (increases) adjustments in fare price, in isolation or aggregated with internal and/or external factors, such as service coverage, quality, and fuel cost.

A number of recent studies examine the effects of offering discounted or free bus passes to university and college students who commute to campus, a policy that has produced notable ridership growth in particular localities. Studies find the arrangement works well in several ways. Density of destination points (the campus) is a given, with service (usually bus) already present or easily added to existing routes. In contrast to the difficulties that attend efforts to implement pro-transit policy in municipalities, at universities a single authority regulates factors related to auto use, such as the availability of parking. Universities benefit if increased transit use reduces traffic on and around campus; they may also be able to repurpose land set aside for parking. Studies report that reduced fares are associated with significant increases in ridership on participating transit systems, strengthening the fiscal stability of municipal transit providers. Finally, reduced fare programs allow researchers to study determinants of ridership change in a relatively controlled microenvironment with abundant and accessible data (Sandidge 2011; Boyd et al. 2003; Brown et al. 2001; Volinski 2012; Dorsey 2005; Zhou 2012).

Studies measuring the influence of fare on ridership may focus on various adjustments such as transit pass incentives (Zhou and Schweitzer 2011), fare increases (Hickey 2005), or simplification of fare pricing (Taylor and Carter 1998). Other studies assess the effects of transit fare on service coverage (Armbruster 2012), transit supply, employment, and gasoline price (Varley and Chen 2010; Pucher 2002). Studies generally found that maintaining or expanding service extent or quality was more strongly and enduringly associated with increased ridership than fare reductions. A study of the relative influence of fuel cost and transit fare on ridership (1996-2009) similarly found that rising gas prices had a more significant effect than decreased transit fares (Chen et al. 2011).

Studies concerned with the effect of transit service on ridership may focus on supply, extent, orientation pattern, and/or quality; the latter may include travel time, punctuality, comfort, safety, and so on. Studies tend to agree that service coverage/extent, frequency, and reliability are among the most significant determinants of transit mode choice. Sweet and Chen (2011) found evidence for travelers choosing transit over automobile commutes where transit was a faster and punctual alternative to traffic congestion. An international comparative study of transit use found that high levels of service (frequency, reliability, and destination proximity) were major drivers of light-rail use in Europe, North America, and Australia (Currie et al. 2011). Thompson and Brown found that service coverage and frequency best explained ridership growth in metropolitan service areas with populations from 1 to 5 million in western US (Thompson and Brown 2006). A study focused on time parameters of service found that extending service in the evening hours had an unexpected and immediate positive effect on afternoon boardings, possibly indicating the sudden viability of transit commutes for workers with evening shifts (Currie and Loader 2009).

Transit orientation refers to how transit systems configure and connect resources to fulfill perceived coverage needs of riders or municipalities. Again, "traditional" system orientation involves transit lines radiating out from a CBD, the presumed, conventional site of greatest employment density. As discussed above, a number of studies conducted over roughly the last decade argue that radial transit systems fail to accommodate the needs of sprawling, low-density cities, many of them in the western US (Thompson and Matoff 2003). The studies argue that low-density metropolitan areas may achieve best results by using flexible bus routes to connect transit-dependent individuals with the dispersed employment sites – a characteristic of postwar, auto-centric urban growth (Brown and Thompson 2012; Thompson and Brown 2012a; Brown and Thompson 2008b; Brown and Thompson 2008c; Majumdar 2010; Deka 2002).

CONCLUDING REMARKS ON REVIEWED LITERATURE

Based on the analysis of demographic and socioeconomic trends, some researchers predict that transit ridership will continue to grow if it is supported by public policies that disincentivize auto use (Millar 2012). Studies that find external factors to be the primary determinants of ridership also identify policy disincentives for driving as the key missing component in increasing transit travel mode share (Taylor and Fink 2003).

Many researchers see land use as a key determinant of transit ridership demand relative to travel demand by automobiles, often in terms of the avowed necessity of high population and employment density to operate efficient transit systems. Recent research suggests that some transit systems may achieve greater success in connecting transit-dependent riders with employment and other necessities—by designing flexible bus systems to match existing configurations of transit-dependent riders and dispersed employment sites (Thompson and Brown 2006). Additionally, studies of the effect of the rising cost of gasoline on transit ridership suggest fuel cost has a significant budgetary impact on low-income drivers, prompting some to become transit users, if only temporarily (Lane 2010).

Studies of socioeconomic factors confirm that the majority of transit riders are low-income, African Americans, Latinos, recent immigrants, women, and older adults, who are unable to either afford an automobile due to financial constraints or use it due to physical conditions. Many researchers see chronic inequity in the allotment of public transit financial resources, particularly in funding rail projects intended to attract middle-class riders over bus systems that serve lower income groups.

Studies of internal determinants generally find that fare reductions, increased service coverage, and service quality are associated with increased ridership. Studies have found that reduced fare programs for university students may increase ridership, but effects of fare price adjustments (increases or reductions) are consistently found to be less significant than the effects of service extensions or rising fuel cost. Increased transit service coverage and quality, e.g., short headways and extended hours, are generally found to be the system factors most associated with increased ridership.

Based on the literature findings within the theoretical framework, the authors selected factors believed to influence transit travel demand for inclusion in this study. The next chapter describes these factors in detail.

III. RESEARCH METHODOLOGY

This chapter explains the study area, presents a conceptual diagram of transit demand analysis, discusses selection of regression model, and describes the data sources and collection methods. In addition, it discusses the independent variables, explains the dependent variable and, finally, presents a discussion on multicollinearity.

STUDY AREA

As mentioned earlier, the authors chose US MSAs as the geographic unit of analysis. The authors collected data from the National Transit Database (NTD 2013) on all 358 MSAs in the lower 48 states. The Metropolitan Area Program of OMB has been providing standard statistical area definitions for more than 60 years. In the 1940s, it became clear that using a single set of geographic definitions for the large population and commerce centers would greatly facilitate the collection, tabulation, and publication of national statistics. When the program began, the OMB established the general concept of an MSA as "an area containing a recognized population nucleus and adjacent communities that have a high degree of integration with that nucleus" (OMB 2000: p. 82228). Unlike the definition of UZA that classifies the counties into urban or rural areas, an MSA includes all counties that contain both urban and rural territories and populations. To ensure the standards' accuracy and relevance, the standards are reviewed periodically. While the Census Bureau updates the list of metropolitan and micropolitan statistical areas every year, the OMB revises the standards of definition every ten years.

CONCEPTUAL DIAGRAM OF TRANSIT DEMAND ANALYSIS

Based on the understanding of the existing literature and theories, this section develops a conceptual model to indicate the relationship between transit travel demand and its determining factors. Figure 2 depicts the theoretical relationships between such factors and transit travel demand. The variables, their selection, and their importance in determining transit demand are discussed in "Explanation of Independent Variables" later in this chapter.
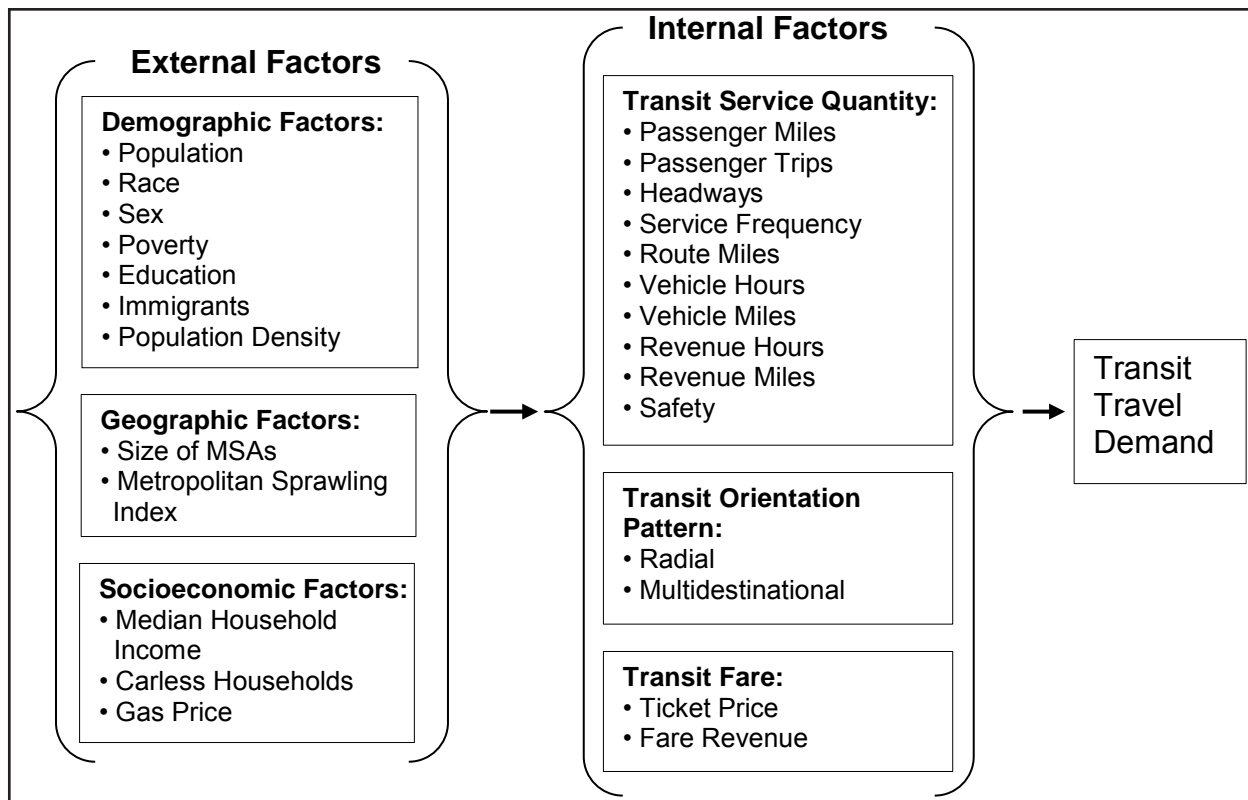
Figure 2.   Conceptual Diagram of Transit Demand Analysis
Source: Adapted from Taylor et al. (2009) and Thompson and Brown (2006).

SELECTION OF REGRESSION MODEL

Some believe that transit supply and demand are jointly produced and therefore affect each other simultaneously. They also believe that this simultaneity between transit supply and demand can lead to inaccurate and biased coefficients of independent variables. Taylor et al. (2009) argue that placing these two variables in the same equation could produce a slope that appears larger than it actually is. To address the simultaneous relationship between transit supply and demand, they constructed two-stage least-squares (2SLS) simultaneous equation models in their cross-sectional analysis of transit use in 265 US UZAs. First, to obtain the estimated values of transit supply, they regressed transit supply on all exogenous variables while ignoring transit demand. Next, they regressed transit demand on the estimated transit supply and all other exogenous variables. McMullen and Eckstein (2013) applied this technique in their panel study of 87 US urban areas to determine the vehicle miles traveled (VMT) between 1982 and 2009.

Other researchers believe that transit supply relatively quickly increases demand for transit, as measured by ridership. But increased demand does not necessarily enhance supply in the context of a cross-sectional time frame. Transit planners would create more supply over a long period where they perceive greater demand, but that process generally takes years. Thompson and Brown (2006) argue that empirical results do not support the theory that transit supply and transit demand are jointly produced and, thereby, might not have reciprocal impacts on each other, concluding that usage of 2SLS model in transit ridership

studies is unnecessary. Therefore, they use ordinary least-squares (OLS) regression to estimate the transit travel demand change between 1990 and 2000. Controlling for possible simultaneity between transit supply and demand, Liu (1993) applied and compared 2SLS and OLS regression models to determine transit demand but found that applying the two techniques yielded no significant differences in the results. The authors of this study believe, similarly to Thompson and Brown (2006), that transit supply and transit demand may have reciprocal relationships over a longer period but not for cross-sectional data over a short period of time. Therefore, the authors of this study used the OLS regression model to determine the factors that significantly impact transit travel demand by bus mode.

DATA SOURCES AND COLLECTION METHODS

The data for this study comes from two major sources: the US Census Bureau (2010) and the Integrated National Transit Database Analysis System (INTDAS 2012). An advanced research tool called American FactFinder was used to extract a wide array of external factors from the Census Bureau's database. The INTDAS is an Internet-accessible database system designed for retrieval and analysis of data from the NTD for the years 1984 to 2010. The system is part of the Florida Transit Information System (FTIS), which was developed by the Public Transit Office of the Florida Department of Transportation (FDOT) and the Lehman Center of Transportation Research (LCTR) at Florida International University in 2000. Several internal factors were directly obtained from the NTD.

The authors constructed a few new variables by dividing, i.e., normalizing one variable by another. They further constructed other variables by conducting a survey, visually inspecting transit systems network maps, and gathering data from websites other than the Census Bureau and NTD websites. For example, because the authors could not directly determine the orientation pattern of a transit system from any database, they designed a survey questionnaire (Appendix A) to obtain this information and sent it to all transit systems managers in the country. There were three main phases in the process of collecting the transit orientation data. First, survey letters were emailed to MSA transit agency managers. Then the letters were emailed for the second time to the agencies that did not respond. Finally, transit agency operators and managers that did not respond to the first and second rounds of the survey were telephoned. About 25 percent of the transit authorities responded to the survey, and 15 percent of the transit authorities provided answers by phone. The authors were able to determine the orientation pattern of ten percent of the systems without using the survey, either because it was stated on the website or the network pattern maps were clear. The orientation patterns for the remaining transit authorities (approximately 50 percent) were determined by the researchers' visual inspection of the transit systems.

Unlike previous studies that used the gas price index (Chen et al. 2011; Kohn 2000; Lane 2010; Lane 2012), the authors of this study collected the absolute values of gas prices from charts provided by the GasBuddy website (GasBuddy 2013) because the gas price index data was available for only 26 MSAs throughout the country. Although the Bureau of Labor Statistics (BLS) has a consumer index, most of the data is presented at the state level. GasBuddy is a public website dedicated to daily recording and presenting the gas prices reported by gas station customers. In addition, the authors estimated Metropolitan Sprawling Index (MSI) values for the MSAs based on the raw data at county level in 2010.

Table 1 displays the variables that were collected and initially considered for this study, corresponding data sources, and the collection or computing methods for obtaining the variables.

Table 1. Variables, Data Sources, and Collection Methods

Variables	Data Sources	Collection Methods
Transit Travel Demand*	NTD	Passenger Miles/MSA Population
Transit Supply	NTD	Vehicles Miles/MSA Population
MSA Size	Census Bureau	Directly obtained from Census Bureau
MSA Population	Census Bureau	Directly obtained from Census Bureau
Population Density	Census Bureau	MSA Population/MSA Size
Median Household Income	Census Bureau	Directly obtained from Census Bureau
African American Population	Census Bureau	Directly obtained from Census Bureau
African American Women Population	Census Bureau	Directly obtained from Census Bureau
Asian Population	Census Bureau	Directly obtained from Census Bureau
Asian Women Population	Census Bureau	Directly obtained from Census Bureau
Hispanic Population	Census Bureau	Directly obtained from Census Bureau
Hispanic Women Population	Census Bureau	Directly obtained from Census Bureau
Total Household in MSA	Census Bureau	Directly obtained from Census Bureau
Percentage of Carless Households	Census Bureau	(Number of Carless Households in MSA/Total Households in MSA)X100
Vehicles per Household	Census Bureau	Number of Vehicles in MSA/Total Households in MSA
Percentage of College Population	Census Bureau	Directly obtained from Census Bureau
Percentage of Population in Poverty	Census Bureau	Directly obtained from Census Bureau
Percentage of Immigrant Population	Census Bureau	Directly obtained from Census Bureau
Passenger Miles	NTD	Directly obtained from NTD
Passenger Trips	NTD	Directly obtained from NTD
Transit Orientation Pattern	Survey; Visual Inspection of Transit Network Maps	CBD Oriented Radial Pattern = 0, Multidestination Oriented Grid Pattern = 1
Metropolitan Sprawling Index	Ewing	Estimated based on the county-level data obtained from Ewing.
Vehicle Miles	NTD	Directly obtained from NTD
Vehicle Hours	NTD	Directly obtained from NTD
Revenue Hours	NTD	Directly obtained from NTD
Revenue Miles	NTD	Directly obtained from NTD
Route Miles	NTD	Directly obtained from NTD
Fare Revenue	NTD	Directly obtained from NTD
Transit Fare	NTD	Fare Revenue/Passenger Trips
Average Headway	NTD	Directly obtained from NTD
Service Intensity	NTD	Vehicle Miles/Route Miles
Safety	NTD	Directly obtained from NTD
Gas Price	Gasbuddy.com	Obtained from gas price chart
MSAs in the West	NTD	Directly obtained from NTD
MSAs in the South	NTD	Directly obtained from NTD
Rail Transit	NTD	Directly obtained from NTD
Transit Coverage	NTD	MSA Population/MSA Route Miles

Dependent Variable.

EXPLANATION OF INDEPENDENT VARIABLES

Based on the understanding of existing literature and theories, this study initially considered a wide array of variables, as shown in Table 1, to determine the factors that significantly impact transit travel demand by bus mode. This section presents a description of these variables. The section explains the external variables followed by the internal factors. The final model includes a subset of the variables explained below.

Explanation of External Variables

MSA Population

General economic theory suggests that the demand for a commodity will increase with the increase in population. To some degree, the population of an MSA determines the number of potential transit users. It is expected that number of potential transit users will rise with an increase in MSA population. Most of the previous studies explored the influence of a study area's population on transit ridership (Chen et al. 2011; Lane 2010; Lane 2012; Sanchez 1999; Forkenbrock et al. 2001; Taylor et al. 2002; Taylor and Fink 2003; Taylor et al. 2009; Brown and Thompson 2008b; Brown and Thompson 2008c; Brown and Thompson 2012; Gutierrez et al. 2011; Brown and Neog 2008; Thompson et al. 2006; Crane 2008; Neog 2009).

MSA Size

Another important factor that one would expect to influence the demand for travel by transit is the physical size of the MSA. Since larger MSAs typically have larger populations, general economic theory suggests that larger MSAs will create more demand for transit travel than their smaller counterparts.

Population Density

As mentioned above, both the population and size of MSAs are important factors that impact the transit ridership level. However, it may not be sufficient to consider their individual influences. Therefore, in this study, in addition to testing the significance of MSA population and MSA size as individual independent variables, the relative influence of population and size, i.e., population density, is also employed. It is expressed as the ratio of MSA population to MSA size, and measured per square mile. Similar to the cases of MSA population and MSA size, it is expected that higher population density will attract more riders to transit.

Median Household Income

As one of the important socioeconomic factors, the median household income represents the economic conditions of a geographic unit. Typically, this variable shows significant influence on transit ridership—the lower the income, the greater the demand for transit ridership (Alam 2009; Thompson and Brown 2006).

Total Households

A large number of households in a geographic unit could mean people at different income levels: wealthy, middle-income, and poor, but it could also mean an abundance of small, poor households. Areas with more households generally imply a larger pool of potential demand for transit service from the lower middle-class and poor segments.

Percentage of African American Population

When planning a new route, the transit authorities are required to submit a Title VI report to the Federal Transit Agency (FTA) proving that the rights and benefits of the poor and minorities were given highest-priority consideration in the planning process. Moreover, the report must demonstrate that the proposed route does increase transit accessibility for minorities. This study used the proportion of African American population to reflect the minority population groups. It is expressed as the ratio of African American population to total population in an MSA. Literature suggests that a substantial proportion of African American minority population ride transit (Alam 2009). Hence, it is expected that the demand for transit travel in a typical MSA will increase with an increase in the proportion of African American population.

Percentage of Carless Households

Unlike car owners who can choose whether or not to use public transportation, people without cars are compelled to use transit for their travel. To some extent, the percentage of carless households reflects the economic conditions of a geographic unit. Considering that the carless data is available only at the household level in the Census Bureau database, this study uses the percentage of carless households instead of carless population. The percentage of carless households is expressed as the ratio of number of carless households to the total number of households in an MSA. A higher percentage of carless households is expected to create an increase in transit travel demand.

Vehicles per Household

Vehicles per household is considered as an important determining factor for transit travel. It is expected that the demand for transit will go down with the increase in vehicles per household. Hence, a negative association is expected between this variable and travel demand by bus.

Percentage of College Population

Percentage of college population is defined as the total number of college-going population divided by the total population of each MSA. There are two reasons to include the percentage of college population in the study. First, by necessity, most college students live at or around campus, where their activities are usually concentrated. Hence, it is not necessary for many of them to possess a car. Second, the cost of owning a car is high relative to the financial resources of most college students. While many colleges and universities have transit passes built into their student fees, many do not. Therefore, it

is important to include this variable in the study of transit demand analysis. A positive relationship is expected between percentage of college population and transit demand.

Percentage of Population in Poverty

As regulated by the FTA, another important group requiring special attention from transit authorities is the poor—not only to ensure equal rights and benefits but also because they are typical transit users. The Census Bureau website identifies populations below poverty level. The poor depend on transit for their travel needs because they cannot afford to purchase and maintain automobiles. It is therefore expected that an increase in percentage of the population in poverty will correspond to an increase in the demand for travel by transit.

Percentage of Immigrant Population

The United States accepts a large number of immigrants each year. A small proportion of them are highly skilled and educated, but a substantial proportion are members of the labor-force. This population usually has a relatively low income and therefore depends on transit for their daily travel. Thus, it is important to consider this group in the analysis of transit demand. It is expected that an increase in percentage of immigrant population will increase transit travel demand.

Gas Price

Studies (Chen et al. 2011; Kohn 2000; Lane 2010; Lane 2012) that tested the influence of gas price on transit ridership have used the gas price index obtained from the BLS. Unfortunately, most gas price indices provided by BLS are presented at the state level, and the data is available for only 26 of the 358 MSAs in the country. The authors of this study instead collected absolute values of gas prices from GasBuddy.com, a public website in which gas station customers in major cities post the station's prices on the site. Each MSA contains one socioeconomic core city or county. Thus, it is reasonable to believe that the core city's gas price represents the corresponding MSA's gas price level. It is generally believed that many drivers switched to riding transit due to gas price hikes during the economic downturn over last decade, suggesting a positive relationship between gas price and transit travel demand.

Metropolitan Sprawling Index

Although MSI has not been used in any study related to public transportation, this study included it because the MSI measures the degree of urban sprawl, not only from a geographical perspective but also from a socioeconomic perspective. The index measures the density of human activities at a certain geographical scale. The MSI consists of four factors: density factor, mix factor, center factor, and streets factor (Ewing et al. 2003). The data for MSI for 2010 provided by Ewing was at the county level. In order to match the geographic unit in this study, the 2010 MSI calculation was based on the methodology explained in Ewing's technical report (Ewing et al. 2003). The higher the MSI value, the less an MSA is said to have "sprawled." And one would expect that the less an MSA is

sprawled, the greater the demand for transit. Hence, the MSI is expected to cause positive impacts on transit travel demand.

MSAs in the South

Recent studies indicate that with the exception of cities like New York, where transit supply and demand are still high, transit use is declining in the Midwest and Northeast relative to the population of these regions (Thompson and Brown 2006). The demand for transit has been on the rise in the South and the West in recent years (Taylor et al 2009; Thompson and Brown 2006). This may be due to several causes, including sociodemographic change due to a huge influx of immigrants to these two regions. The authors included a dummy variable called "South" to test if MSAs in this region make any difference in transit demand. Initially, a dummy variable for MSAs in the West was also included, but the final model included only MSAs in the South.

Rail Transit

The presence of rail transit in an MSA may influence transit ridership by bus mode. Many riders may drive to the rail station, park at the station, and take a train to their destinations. Similarly, bicyclists may bike to train stations, board the train with their bikes, then, after exiting the train, bike to their final destinations. Others, however, may take the bus to and from the rail stations to meet their derived travel demand. Yet, others may decide to use only train mode and not ride the bus at all. The authors included a dummy variable that indicates the presence or absence of rail transit in the MSAs. It is expected that the presence of rail transit in an MSA will reduce the demand for travel by bus. It is measured dichotomously: 0 = absence, while 1 = presence of rail transit.

Explanation of Internal Variables

Vehicle Miles per Capita

Vehicle miles per capita is estimated as the total distance traveled by buses, as measured by the total annual bus mileage within and outside the route map, divided by total MSA population. As defined by this study, this variable constitutes transit supply. As mentioned earlier, the demand for transit travel increases when transit managers increase transit supply; hence, a positive relationship is expected between vehicle miles per capita and transit demand.

Revenue Miles

Unlike vehicle miles, revenue miles are limited to bus mileage within the route map over a year's time, i.e., miles that buses travel while in revenue service. This variable is smaller than vehicle miles because it excludes non-revenue miles. Non-revenue miles are generally the miles not on the route map, such as the miles between the central garage and the bus stop. Like vehicle miles per capita, an increase in revenue miles is associated with an increase in transit demand.

Route Miles

Route miles are defined as the mileage traveled by buses in each direction over routes. In other words, it is the mileage in each direction of the roadway over which buses travel while in revenue service. It includes the length of a roadway segment but excludes services provided on the roadway, such as number of lanes or number of buses. An increase in route miles is expected to cause greater demand for transit travel.

Service Intensity

The ratio of vehicle miles to route miles is another important variable constructed by the authors. To some extent, it measures the service intensity, or frequency, of transit systems. Since vehicle miles include total annual bus mileage of both within and *outside* the route map, the higher the value of the ratio—i.e., the more vehicle miles relative to route miles— the greater the proportion of service *outside* the route map—the less frequent the service *within* the route map and, thus, the decrease in the service quality. It is expected that an increase in this ratio, i.e., a decrease in the quality of service in terms of frequency/ intensity *within* the route map, will decrease the demand for transit. As such, a negative association is expected between service intensity and transit travel demand by bus.

Vehicle Hours

As with vehicle miles that measure the total distance traveled by buses, vehicle hours count the total hours of operation of transit service, including both revenue and non-revenue hours.

Revenue Hours

Revenue hours are the total hours of operation along passenger service routes. It excludes those hours that the buses operate not for passenger services. An increase in both vehicle hours and revenue hours is expected to cause an increase in transit travel demand.

Average Headway

Measured as the distance from the tip of one bus to the tip of the next bus, average headway is also measured as the time the trailing bus takes to cover the distance between its tip and the tip of the front bus. For this study, it is measured in minutes. A longer headway indicates less frequent or less efficient transit service. Traffic theory suggests that demand for transit travel will decrease with an increase in average headway; hence, a negative association is expected between this variable and transit travel demand.

Safety

"Safety" is defined by NTD as a measure of the reported number of incidents/accidents involving transit vehicles. An accident is defined as an incident involving a transit vehicle that results in casualty, collision, or property damage in excess of $1,000. More number of incident/accident reporting indicates that the transit system is less safe for the riders, which

decreases their confidence in the transit system. One would expect that this decreased confidence in the safety feature of the transit system would eventually decrease the demand for transit. Hence, a negative association is expected between this variable and demand for transit.

Transit Fare

General economic theory suggests that the demand for a commodity will decrease if its price increases. Several previous studies, such as Taylor et al. (2009), have tested the influence of transit fare on patronage and found that when the transit fares increase, ridership decreases. Transit fare is calculated as the ratio of passenger fare revenue to the total number of passenger trips.

Transit Coverage

Transit coverage is expressed as the ratio of MSA population to route miles. One would expect that the greater the ratio of population to route miles, the larger the unserved population and, thereby, increasing the demand for transit. Hence, a positive association is expected between transit coverage and transit demand.

Transit Orientation Pattern

There are two polarized route structures for transit orientation patterns (Thompson and Matoff 2003). One extreme is the traditional CBD-oriented radial pattern. Transit managers who operate this kind of system typically focus on attracting customers to the CBD, which they believe is the largest market for transit service (Alam, Thompson, and Brown 2010; Brown and Thompson 2008b). Route structures that accomplish this objective have more routes converging into the CBD. Figure 3 is a conceptual diagram of CBD-oriented radial transit systems. Figure 4 represents the transit system map for Roanoke, Virginia MSA, which demonstrates a typical radial transit pattern in the real world. Another extreme is the multidestination-oriented grid pattern. Transit managers who adopt this type of system are usually dedicated to helping customers reach multiple destinations without transferring. Thus, a distinguishing difference between the radial and grid pattern is the need to transfer (Brown and Thompson 2008b). Figure 5 shows a conceptual diagram of the grid-pattern transit system. Figure 6 represents the transit system map for Odessa, Texas MSA, which demonstrates a grid-pattern transit system in the real world. Transit orientation pattern is encoded dichotomously: CBD-oriented radial pattern = 0; multidestination oriented grid pattern = 1. Since the multidestination-oriented grid pattern provides direct service from origins to destinations, it is generally considered the more efficient of the two patterns and, thereby expected to create more demand for transit travel. Hence, a positive relationship is expected between transit orientation pattern and transit travel demand, which will indicate that the more the multidestination-oriented transit systems, the more the demand for travel by transit will be.
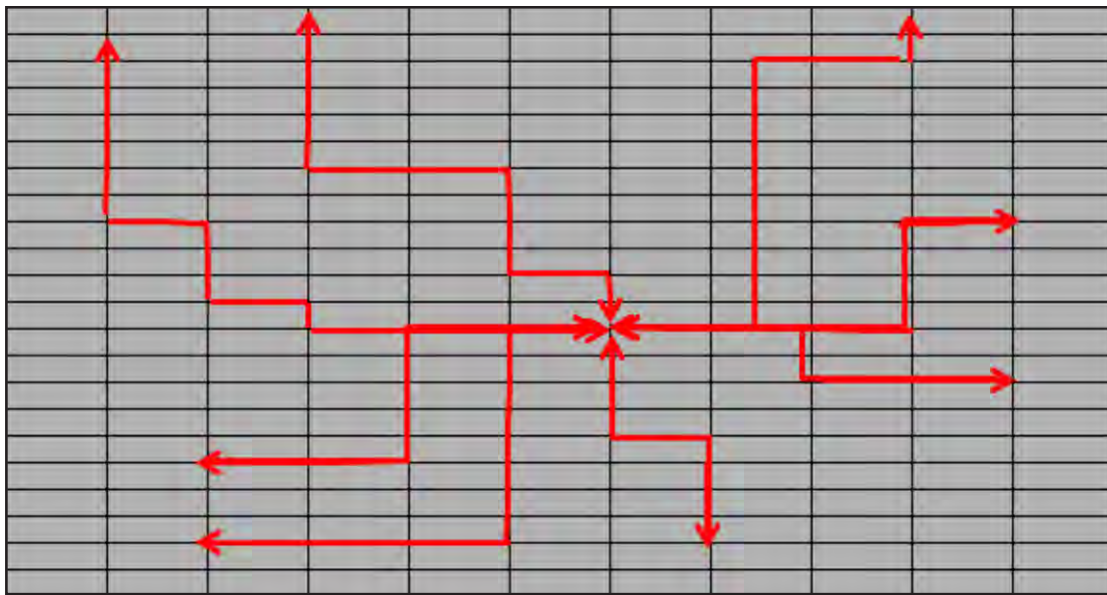
Figure 3.   Conceptual Diagram of the CBD-Oriented Radial Pattern Transit System
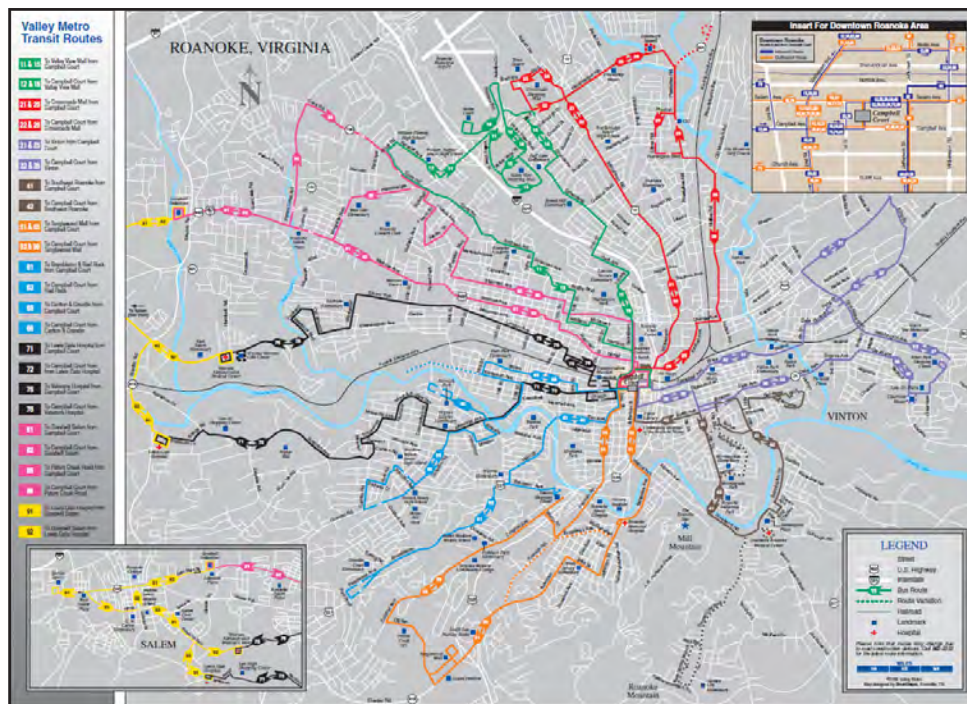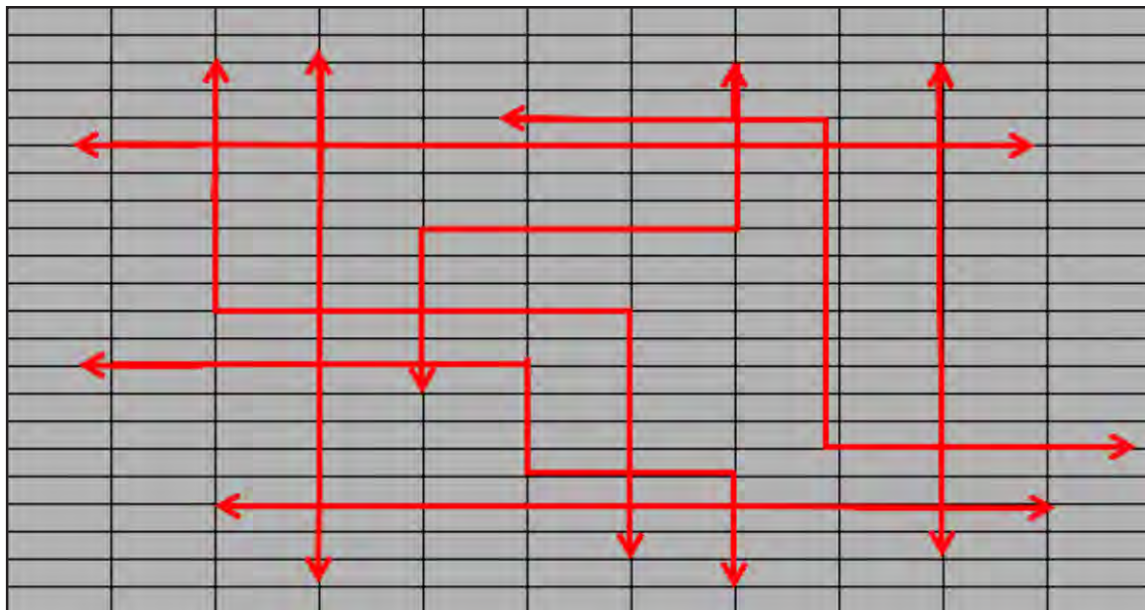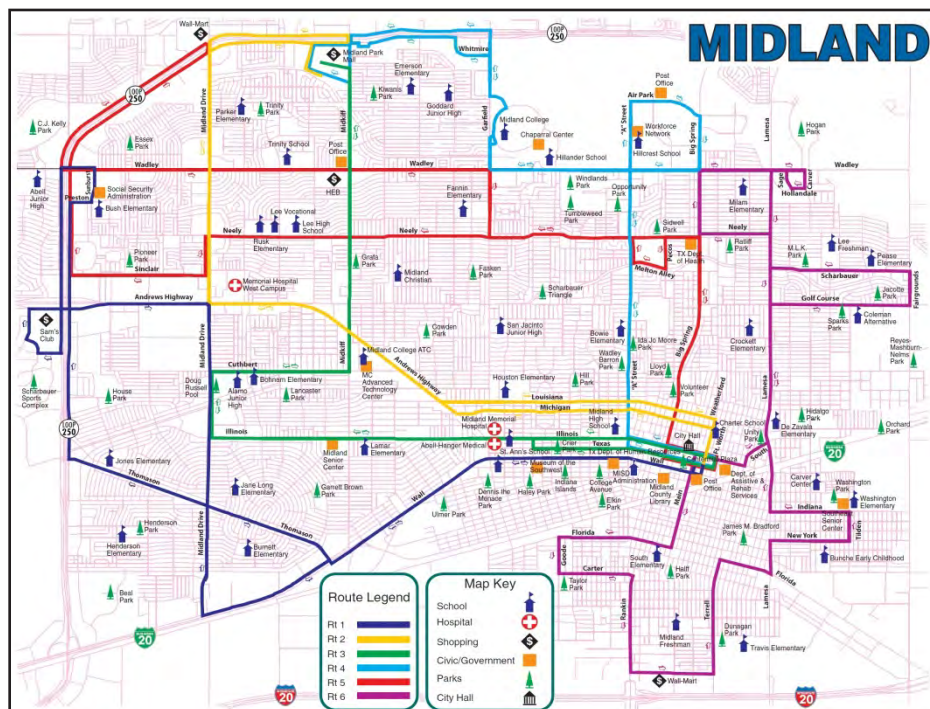

Figure 4.   Example of a CBD-Oriented Radial Pattern Transit System
Image Source: Roanoke, Virginia MSA (www.valleymetro.com)

Figure 5. **Conceptual Diagram of the Multidestination-Oriented Grid Pattern Transit System**

Figure 6. **Example of a Multidestination-Oriented Grid Pattern Transit System**

Image Resource: Odessa, Texas MSA (www.ez-rider.org)

EXPLANATION OF THE DEPENDENT VARIABLE

"Passenger trip" is defined as an event in which a passenger boards a bus. One trip is counted for each boarding. If a passenger makes a bus trip that involves one transfer, two passenger trips are counted—one for each time the passenger boarded a bus. The

authors initially constructed passenger trips per capita, which is obtained by dividing total passenger trips in an MSA by the population of the respective MSA. They also constructed a variable for average passenger miles, which is estimated by dividing the total passenger miles by total trips in an MSA. It is a proxy measure of the distance the passengers travel. Initially, the authors thought of using passenger trips per capita as a measure of transit travel demand. They also ran their models using average passenger miles as the proxy for transit travel demand. However, their preliminary results, as reflected by the F statistic and coefficients of multiple determination, indicated that passenger miles per capita was a more appropriate measure of transit demand than passenger trips per capita or average passenger miles. Therefore, the authors used passenger miles per capita as the dependent variable in their final model.

DISCUSSION ON MULTICOLLINEARITY

The objective of the multiple linear regression model is to quantify how the dependent variable is associated with multiple independent variables. If the relationships among any pairs of independent variables are stronger than the relationship between the dependent variable and the independent variables, the change in one independent variable will cause a corresponding change in another independent variable. Then, the estimation of the parameter b will not be accurate because it violates the assumptions of linear regression. This phenomenon is called multicollinearity.

Multicollinearity can lead to inaccurate results by decreasing the stability of the regression models. There are three methods to identify multicollinearity:

1. Construction of a scatterplot matrix of the dependent variable with all the independent variables. A very highly correlation among quantitative predictors indicates a potential multicollinearity problem.

2. Calculation of the correlations between the dependent variable and each of the independent variables, and between each pair of independent variables. Potential multicollinearity exists if any of the correlations between each pair of predictors is greater than the correlation between the dependent variable and each independent variable.

3. The use of variance inflation factors (VIF) that quantify the severity of multicollinearity by measuring how much the variance of each estimated regression coefficient is increased due to the existence of a correlated predictor in the same model (Pardoe 2006; Gujarati and Porter 2008; Gujarati and Porter 2009). The greater the collinearity between a regressor and other regressors in an OLS model, the higher the VIF value (Gujarati 2011). Tolerance (TOL), the inverse of VIF, is also used by some scholars to show the presence of multicollinearity among the regressors. The higher the VIF value, the lower the TOL. Therefore, when the VIF of a regressor increases toward infinity or TOL decreases toward zero, it indicates a high correlation between the variable and the other independent variables in the OLS model.

To address the presence of multicollinearity, Pardoe (2006) provides the following three solutions: a) collecting new similar data with lower correlation with other predicators, b) combining the correlated variables to form one new variable, and c) removing one of the pairs of correlated variables from the model. The authors applied these three techniques to identify and address the presence of multicollinearity among the predictor variables in the regression model. The final model contained only those theoretically driven variables that did not have high collinearity.

IV. RESULTS AND ANALYSIS

This chapter presents the descriptive and statistical results of the study. Initially, the authors regressed passenger miles per capita on a wide array of variables. Multicollinearity was detected among a few variables, so these were eliminated. The final model comprises the theoretically suggested variables that determine transit ridership. Table 2 shows the descriptive statistics of the variables going into the final OLS regression model. Although the authors collected data on all 358 US MSAs, 85 were eliminated due to missing values, leaving 273 for analysis with the final regression model.

Table 2.   Descriptive Statistics of the Variables Going into the Regression Model[a]

Variables	Mean	Std. Dev.
Passenger Miles per Capita	41.908402	84.0401825
Population Density	306.994413	346.4363770
Rail Transit	.1392	.34678
Gas Price	1.3707	1.37436
Transit Orientation Pattern	.31	.464
Metropolitan Sprawling Index	101.322606	27.4137338
Median Household Income	47645.168498	8036.7492354
Percentage of African American Population	10.626007	10.8087834
Percentage of Carless Households	7.170875	2.4528409
Vehicles per Household	.978864	.0921752
Percentage of College Population	8.894854	4.5150755
Percentage of Immigrant Population	4.991012	4.3542533
Transit Fare	.194811	.1366341
Transit Supply	6.085164	6.6990366
Revenue Hours	453217.659341	1323667.46989
Average Headway	63.582308	78.0623526
Safety	45.952	148.7526
Transit Coverage	1638.8776	2172.42650
MSAs in the South	.3590	.48058
Service Intensity	7210.1188	6321.45197

[a] *Dependent Variable:* Passenger Miles per Capita.

Table 3.   Regression Results Showing Impacts of Explanatory Variables on Transit Travel Demand[a]

Variables	Unstandardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	t	Sig.
(Constant)	-.509	27.142		-.019	.985
Population Density	.000	.009	-.001	-.014	.989
Rail Transit	-3.419	6.216	-.014	-.550	.583
Gas Price	3.630	1.357	.059	2.675	.008
Transit Orientation Pattern	2.266	3.858	.013	.587	.557
Metropolitan Sprawling Index	-.030	.081	-.010	-.371	.711
Median Household Income	.000	.000	-.015	-.538	.591
Percentage of African American Population	.018	.185	.002	.096	.923
Percentage of Carless Households	-1.517	.998	-.044	-1.519	.130
Vehicles per Household	-2.327	21.150	-.003	-.110	.912
Percentage of College Population	.420	.382	.023	1.101	.272
Percentage of Immigrant Population	.638	.446	.033	1.429	.154
Transit Fare	-24.360	12.389	-.040	-1.966	.050
Transit Supply	12.695	.277	1.012	45.831	.000
Revenue Hours	1.070E-005	.000	.168	3.536	.000
Average Headway	-.055	.023	-.051	-2.338	.020
Safety	.060	.021	.106	2.871	.004
Transit Coverage	.004	.001	.116	5.272	.000
MSAs in the South	2.102	4.297	.012	.489	.625
Service Intensity	-.004	.000	-.321	-10.196	.000

[a] *Dependent Variable:* Passenger Miles per Capita.

The R^2 (coefficient of multiple determination) and adjusted R^2 values for the model are 0.907 and 0.900, respectively, which indicates that the external and internal explanatory variables selected for this study explain about 90 percent of the variability in the dependent variable, passenger miles per capita. The F statistic for the model is 130.034 with a significance level of 0.000, which shows that the model fit was good.

Table 3 shows the regression results. The results indicate that gas price, transit fare, transit supply, revenue hours, average headway, safety, transit coverage, and service intensity show statistically significant impacts on transit demand by bus. Among these, transit supply causes the highest impact on transit travel demand in the expected direction: the greater the supply, the greater the demand for transit. Also, gas price, transit fare, revenue hours, average headway, service intensity, and transit coverage show significant impacts on transit demand in the expected direction. A greater number of revenue hours indicates better and more frequent service, which will result in more demand for transit. The authors' study supports this hypothesis. General economic theory suggests that drivers will choose public transit over driving automobiles when gas prices rise, which is supported by this study. Similarly, existing studies and general economic theory suggest that the demand for transit will go down as the transit fare goes up. For US MSAs, at least, this study provides further proof: an inverse relationship exists between transit fare and transit demand. A

similar inverse relationship exists between average headway and transit demand. Average headway is the time needed by a vehicle to cover a distance between the tip of the preceding vehicle to the tip of the following vehicle. The shorter the average headway, the greater the frequency of vehicles crossing a given point on a roadway segment per hour or day, which, all else being equal, leads to an eventual increase in transit demand. The current study supports this theory and indicates that the demand for bus transit increases with the decrease in average headway. Service intensity shows significant impacts on transit demand in the expected direction as well. As explained earlier, this study defines service intensity as the ratio of vehicle miles to route miles. Vehicle miles include bus miles *within* and *outside* the route maps, while route miles include bus miles *only within* the route map. Hence, a larger ratio of vehicle miles to route miles indicates more bus miles *outside* the route map because bus miles *within* the route maps are equal in both cases, which further indicates less bus miles *within* the route maps that would lead to less frequent and worse quality service. This worse quality service, in turn, will cause decreased demand for transit. One would, therefore, expect an inverse relationship between service intensity and transit demand. The finding of this study supports this hypothesis. Transit coverage shows significant impacts on demand for transit in the expected direction as well—the greater the transit coverage, the larger the unserved population and, thereby, the greater the demand for transit. In contradiction to the impact of these factors in the expected direction, safety, which is measured as the number of incidents reported per year, shows significant impacts on transit demand in the unexpected direction. The authors expected that a higher number of incident/accident reports would decrease the demand for transit, but the model result indicates otherwise.

The study found that certain variables that many transit planners view as important determinants of transit demand did not have significant impacts on transit demand. For example, one would expect that the MSAs where rail transit is present would show reduced demand for travel by bus. The current study indicates such a result, but the test statistic is not significant. Variables such as transit orientation pattern, median household income, percentage of college population, percentage of immigrant population, vehicles per household, and MSAs in the South behaved as expected. But they also do not impart significant effects on transit demand by bus. On the other hand, population density and the percentage of households without cars show insignificant impacts on transit demand in the opposite of the expected direction.

Overall, the study indicates that the internal variables show signs of causing significant impacts on travel demand by bus transit mode in 2010, while the external factors, with the exception of gas price, do not. It indicates that the socioeconomic factors that are beyond the control of transit managers and operators do not necessarily contribute to the effectiveness and efficiency of transit systems. This simplifies the problem in a sense. It reveals that the job of building ridership belongs to, and is within reach of, policy makers, transit managers and operators, and that to achieve this goal, all efforts should focus on providing better transit systems that work more efficiently.

V. CONCLUSIONS

This study examined the influence of various factors on transit ridership by bus in 2010. To do so, it employed a multiple OLS regression model to find the cause-effect relationships between transit travel demand and determining factors. It used VIF and correlation coefficients to determine multicollinearity among the explanatory variables. A total of 19 variables were regressed on transit demand by bus, as measured by passenger miles per capita. Among these, 8 variables were internal and 11 were external. The results show that the internal variables, the factors that transit managers and operators control, are predominantly the significant predictors of transit travel demand by bus mode. Seven out of eight internal variables in the OLS regression model proved to be significant factors in determining travel demand by bus. The exception was the transit orientation pattern variable. Contrarily, gas price is the only external variable that proved to be a significant predictor for transit demand by bus mode. Among the remaining ten insignificant external variables that were tested, eight demonstrated behavior in the expected direction while population density and the percentage of carless households demonstrated the opposite of the expected behavior. Since transit coverage indirectly measures the impacts of population, it is understandable that population density proved to be an insignificant predictor and that transit coverage was significant. Table 4 displays the explanatory variables going into the final regression model, their expected and observed impacts on transit demand, and the significance of the impacts.

Table 5 provides the summary and comparison among this study and two previous studies carried out by Thompson and Brown (2006) and Taylor et al. (2009). Like Thompson and Brown (2006) but unlike Taylor et al. (2009), this study demonstrates that the internal variables shape the demand for transit by bus mode to a large extent, and that gas price is the only external variable of comparable importance. Unlike Taylor et al. (2009), this study indicates that external variables, such as percentage of carless households, percentage of immigrant population, location in the South, percentage of college population, population density, and median household income, do not prove to have statistically significant impacts on transit travel by bus mode in US MSAs in 2010. The similarity of findings of this study with Thompson and Brown (2006) and dissimilarities with Taylor et al. (2009) can be attributed to the likenesses and differences in research design. The selection of MSAs as geographic units of analysis in this study was similarly used by Thompson and Brown (2006) but not by Taylor et al. (2009). The use of OLS was the same for the study by Thompson and Brown (2006) but, again, differed from Taylor et al. (2009). The selection of passenger miles per capita as the dependent variable was not used by Taylor et al. (2009), but it was by Thompson and Brown (2006).

Table 4. Explanatory Variables' Expected and Demonstrated Impacts on Transit Travel Demand by Bus Mode

External Factors	Expected Behavior	Demonstrated Behavior	
		Sign	Significant?
Rail Transit	Negative	Negative	No
Gas Price	Positive	Positive	Yes
Metropolitan Sprawling Index	Positive	Negative	No
Median Household Income	Negative	Negative	No
Percent of African American Population	Positive	Positive	No
Percent of Carless Households	Positive	Negative	No
Vehicles per Household	Negative	Negative	No
Percent of College Population	Positive	Positive	No
Percent of Immigrant Population	Positive	Positive	No
MSAs in the South	Positive	Positive	No
Population Density	Positive	Negative	No
Internal Factors			
Transit Orientation Pattern	Positive	Positive	No
Transit Fare	Negative	Negative	Yes
Transit Supply	Positive	Positive	Yes
Revenue Hours	Positive	Positive	Yes
Average Headway	Negative	Negative	Yes
Safety	Negative	Positive	Yes
Transit Coverage	Positive	Positive	Yes
Service Intensity	Negative	Negative	Yes

However, the difference between this study and Thompson and Brown (2006) is the selection of a wide array of independent variables, including gas price and metropolitan sprawling index. Another major difference is the study year. While Thompson and Brown (2006) examined the change between 1990 and 2000, this study concentrated on 2010. Yet another major difference is the number of MSAs considered for analysis. Thompson and Brown (2006) selected only those MSAs with population between 500,000 and 5 million, which allowed them to study only 82 MSAs. By contrast, the authors of this study collected data on all 358 MSAs in the nation as of 2010. They dropped 85 MSAs due to missing values, keeping 273 MSAs in the final model.

Although this study does not support the conventional wisdom that external variables, such as population density, cause significant impacts on transit demand, it supports that transit coverage, a constructed variable determined by dividing MSA population by route miles, causes significant impacts on transit demand. It means that although MSA population or population density does not individually impact transit demand, such variables cause impacts while randomized by another variable, such as route miles. It is worthwhile to mention here that both MSA population and MSA size proved to be insignificant predictors in the initial model runs.

The findings of this study are important for transit policy makers, planners, operators, managers, and its stakeholders. Since the study finds that the factors internal to the transit systems predominantly define bus transit demand for the nation at the MSA level, it will largely fall to transit managers and operators to determine how to provide taxpayers with efficient bus transit systems without depending on outside factors. In other words, they can attract and increase bus transit ridership by adjusting a few significant factors specific to their transit systems for which they need not depend on the outside world. Keeping this in mind, transit policy makers and planners may make appropriate plans and policies that will help transit authorities provide efficient transit systems to its users to increase ridership by bus.

Table 5. Comparison of Findings of Thompson and Brown (2006); Taylor et al. (2009); and Alam et al. (2015)

Authors	Study Period	Study Area	Unit of Analysis	Methodology	Dependent Variable	Independent Variables	Significant Variables
Thompson and Brown (2006)	1990-2000	United States (82 MSAs)	MSA	OLS Regression	Passenger Miles Per Capita.	Percent Change in MSA Density Percent Change in Service Frequency Percent Change in Service Coverage West Region Change in Rail Ratio Percent Change in MSA Population Multidestination System Layout Percent Change in Unemployment Rate Percent Change in Hispanic Population Share Percent Change in African American Population Share.	Percent Change in Service Frequency (for All Observation Model; 1,000,000 to 5,000,000 Population Group Model; and 500,000 to 1,000,000 Population Group Model). Percent Change in Service Coverage (for All Observation Model; 1,000,000 to 5,000,000 Population Group Model; and 500,000 to 1,000,000 Population Group Model). West Region (for 500,000 to 1,000,000 Population Group Model) Percent of Routes that Do Not Serve the CBD (for 500,000 to 1,000,000 Population Group Model).
Taylor et al. (2009)	2000	United States (265 UZAs)	UZA	Two-Stage Least-Squares Regression	Vehicle Revenue Hours; Transit Ridership (Total Number). Vehicle Revenue Hours; Transit Ridership (per Capita).	Area of Urbanization Population Population Density Regional Location in US (UZA in the South) Personal/Household Income Unemployment Rate Percent of Population in College Percent of Population in Poverty Percent of Population Recent Immigrants Political Party Affiliations (Percent Democrat) Racial/Ethnic Composition (Percent African American) Fuel Prices Freeway Lane Miles Non-transit/Non-SOV Trips Percent Carless Households.	Predicted Vehicle Revenue Hours Population Density UZA in the South Percent of Population in College Percent of Population Recent Immigrants Percent Carless Households Median Household Income Geographic Land Area Non-transit/Non-SOV Trips Transit Fare Headways/Service Frequency.

Authors	Study Period	Study Area	Unit of Analysis	Methodology	Dependent Variable	Independent Variables	Significant Variables
Alam et al. (2015)	2010	United States (273 MSAs)	MSA	OLS Regression	Passenger Miles Per Capita.	Population Density Rail Transit Gas Price Transit Orientation Pattern Metropolitan Sprawling Index Median Household Income Percentage of African American Population Percentage of Carless Households Vehicles per Household Percentage of College Population Percentage of Immigrant Population Transit Fare Transit Supply Revenue Hours Average Headway Safety Transit Coverage MSAs in the South Service Intensity.	Gas Price Transit Fare Transit Supply Revenue Hours Average Headway Safety Transit Coverage Service Intensity.

APPENDIX A: TRANSIT ORIENTATION PATTERN SURVEY QUESTIONNAIRE

Dear Transit Manager,

We are conducting a research to explore the determining factors for transit travel demand by bus mode in US MSAs. In order to study this important issue thoroughly, we need some data on your transit system. We will appreciate if you could kindly spend 5-10 minutes time to answer the following questions.

Many thanks in advance.

Regards,

The Research Team.

Q1: What was the network pattern of your transit system in 2010?

    CBD-Oriented Radial Pattern   Multidestination-Oriented Grid Pattern

Q2: What was the network pattern of your transit system in 2000?

    CBD-Oriented Radial Pattern   Multidestination-Oriented Grid Pattern

Q3: What was the network pattern of your transit system in 1990?

    CBD-Oriented Radial Pattern   Multidestination-Oriented Grid Pattern

Q4: If there was any re-structuring of your transit system, please identify the kind of re-structuring and the year.

    CBD-Oriented Radial Pattern to Multidestination-Oriented Grid Pattern in Year _____

    Multidestination-Oriented Grid Pattern to CBD-Oriented Radial Pattern in Year _____

Q5: How many stops did your transit system have in 2010? _____

Q6: How many stops did your transit system have in 2000? _____

Q7: How many stops did your transit system have in 1990? _____

APPENDIX B: CALCULATION OF SPRAWLING INDEX FOR TOLEDO METROPOLITAN STATISTICAL AREA

This appendix shows the process to calculate Metropolitan Sprawling Index using Toledo MSA as an example. The step-by-step calculation is shown below.

Step 1: Sum Each Factor for the Toledo Metropolitan Statistical Area

- Density Factor: Density factor represents the residential density in an MSA.

- Mix Factor: Composite factor that includes neighborhood mix of homes, jobs, and services in an MSA.

- Center Factor: Represents the strength of activity centers and downtown of an MSA.

- Street Factor: Street factor measures the accessibility of the street network within an MSA.

Table 6.   Factors of Sprawling Index for Toledo Metropolitan Statistical Area

County Name	Density Factor	Mix Factor	Center Factor	Street Factor
Fulton County	88.613973	128.892486	71.341898	93.647164
Lucas County	105.035406	88.770514	130.025489	116.397647
Ottawa County	90.785378	112.56795	78.658296	94.394117
Wood County	97.144689	113.895771	103.736092	82.107413
Total	381.579446	444.126721	383.761775	386.546341

Step 2: Regress the Four Factors on Toledo MSA's Population

The relationship between the four factors and population is expressed by Equation 1 and Table 7:

$$Y=b_0+b_1S_1+b_2S_2+b_3S_3+b_4S_4 \hspace{3cm} \text{(Equation 1)}$$

Where,

Y = Toledo MSA's Population in 2010 = 651,429

S_1 = Sum of the density factor for Toledo MSA = $\sum D_i$ (Where, D_i = individual county's density factor) = 381.579446

S_2 = Sum of the mix factor for Toledo MSA = $\sum M_i$ (Where, M_i = individual county's mix factor) = 444.126721

S_3 = Sum of the center factor for Toledo MSA = $\sum C_i$ (Where, C_i = individual county's center factor) = 383.761775

S_4 = Sum of the street factor for Toledo MSA = $\sum S_i$ (Where, S_i = individual county's street factor) = 386.546341

Table 7.   Regression Results for Metropolitan Sprawling Index Estimation for Toledo Metropolitan Statistical Area[a]

	Unstandardized Coefficients		Standardized Coefficient		
Model	B	Std. Error	Beta	t	Sig.
(Constant)	-56280.591	67906.986		-.829	.408
Density Factor	3624.352	885.437	.817	4.093	.000
Mix Factor	-6463.041	555.109	-1.289	-11.643	.000
Center Factor	5930.942	1181.138	1.195	5.021	.000
Street Factor	-243.335	802.398	-.052	-.303	.762

[a] *Dependent Variable:* MSA Population.

Step 3: Estimate the Population (Y^)

$$Y^\wedge = b_0 + b_1 S_1 + b_2 S_2 + b_3 S_3 + b_4 S_4 \qquad \text{(Equation 2)}$$

= (-56280.591) + (3624.352*381.579446) + (-6463.041*444.126721) + (5930.942*383.761775) + (-243.335*386.546341)

=638,297.0057

Step 4: Calculate the Standardized Residual

Standardized Residual = Residual/Standard Deviation of Residual   (Equation 3)

Where,

Residual = Y- Y^ = 651,429 – 638,297.0057 = 13,131.9943   (Equation 4)

Standard Deviation of Residual= $\sqrt{\sum(Y-Y^\wedge)^2/(N-2)}$=920,452.9868   (Equation 5)

    Where, N = 358 (total number of MSAs in the country in 2010)

Therefore, the standardized residual for the Toledo MSA is 0.014266882

Step 5 Transform the Standardized Residual

For sprawling index calculation, Ewing et al. (2003) suggests that the standardized residual should have a mean of 100 and standard deviation of 25.

$Z = (X_i - X\text{-bar}) / \text{Standard Deviation}$ (Equation 6)

Where, X_i = Standardized Residual = 0.014266882

$X\text{-bar} = \sum X_i / N = 0.000000242$

Standard Deviation of $X_i = \sqrt{\sum(X_i - X\text{-bar})^2/(N-1)} = 0.99859845$ (Equation 7)

After inserting the values of X_i, X-bar, and Standard Deviation in Equation 6, we get the Z score for Toledo MSA as 0.014287. Then, the transformed score can be estimated using Equation 8 as below:

Transformed Score, i.e., MSI Score = 25*Z score + 100 = =100.3572 (Equation 8)

Therefore, Toledo MSA's MSI score = 100.3572.

ABBREVIATIONS AND ACRONYMS

2SLS	Two-Stage Least-Square
BLS	Bureau of Labor Statistics
CBD	Central Business District
FDOT	Florida Department of Transportation
FTIS	Florida Transit Information System
INTDAS	Integrated National Transit Database Analysis System
LCTR	Lehman Center of Transportation Research
MSA	Metropolitan Statistical Area
MSI	Metropolitan Sprawling Index
NTD	National Transit Database
OLS	Ordinary Least Squares
OMB	Office of Management and Budget
UZA	Urbanized Area
VIF	Variance Inflation Factors

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PEER REVIEW

San José State University, of the California State University system, and the MTI Board of Trustees have agreed upon a peer review process required for all research published by MTI. The purpose of the review process is to ensure that the results presented are based upon a professionally acceptable research protocol.

Research projects begin with the approval of a scope of work by the sponsoring entities, with in-process reviews by the MTI Research Director and the Research Associated Policy Oversight Committee (RAPOC). Review of the draft research product is conducted by the Research Committee of the Board of Trustees and may include invited critiques from other professionals in the subject field. The review is based on the professional propriety of the research methodology.