FINAL REPORT

Project G

January, 2019

Transit in the Era of Shared Mobility

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TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. Project G	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Transit in the Era of Shared Mobility		**5. Report Date** January 2019
		6. Performing Organization Code
7. Author(s) Dr. Kari Watkins, Ph.D., Georgia Institute of Technology Dr. Noreen McDonald, Ph.D., UNC Chapel Hill Dr. Ruth Steiner, Ph.D., University of Florida Dr. Billy Williams, Ph.D., North Carolina State University		**8. Performing Organization Report No.**
9. Performing Organization Name and Address **Georgia Institute of Technology** 790 Atlantic Drive Atlanta, GA 30332-0355 **University of North Carolina-Chapel Hill** New East Building, CB 3140 Chapel Hill, North Carolina 27599-3140 **University of Florida** Architecture Building, 1480 Inner Road Gainesville, FL 32611 **North Carolina State University** 418 Mann Hall Raleigh, NC 27695		**10. Work Unit No.**
		11. Contract or Grant No. Funding Agreement Number 69A3551747104
12. Sponsoring Agency Name and Address University of Florida Transportation Institute Southeastern Transportation Research, Innovation, Development and Education Center (STRIDE) 365 Weil Hall, P.O. Box 116580 Gainesville, FL 32611 U.S Department of Transportation/Office of Research, Development & Tech 1200 New Jersey Avenue, SE Washington, DC 20590 United States		**13. Type of Report and Period Covered** 5/31/2017 to 1/30/2019
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

There are several conflicting trends in the rapidly changing transportation market, which are impacting transit ridership is varying ways. Transportation Network Companies have the potential to reduce or replace the need for auto ownership and may serve some populations better than transitional transit services, but limited survey research indicates that they may be adding more trips than they reduce. With recent surges in technology that negate the need for trips, low gas prices and a strong economy, and shifting populations, fixed route transit ridership is on the decline. However, research on all of these factors is limited and largely inconclusive. While it is useful to track ridership trends at the national level on a city-by-city basis, such analysis only yields limited insight. Ongoing research by the study team compares trends within similar groups of agencies and metropolitan areas. Use of these clusters in ridership analysis suggests that changes in ridership are not uniform across modes and clusters. By conducting disaggregate level research in three cities (Portland, Minneapolis, and Miami), the study team found that the most productive routes are those losing the most ridership. Models also indicated that economic displacement of transit-dependent patrons may be causing ridership to decline in three systems studied. Future research by the research team will extend this work by considering housing prices and ride-hailing usage. At the same time, through this research, the study team encountered various avenues through which innovation in shared mobility is driving the evolution of healthcare transportation. Across the country, care providers are partnering with ridehailing services such as Uber and Lyft to establish new ways for patients to travel to and from medical appointments. While new partnerships and companies continue to emerge in healthcare mobility services, it is important for both healthcare providers and transportation providers to evaluate programs to ensure that they are accessible to the most vulnerable patient populations.

17. Key Words		18. Distribution Statement		
transit ridership; transportation network companies, shared mobility, paratransit,		No restrictions		
19. Security Classif. (of this report)		**20. Security Classif. (of this page)**	**21. No. of Pages** 61 pages	**22. Price**

Form DOT F 1700.7 (8-72)   Reproduction of completed page authorized

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ACKNOWLEDGEMENTS

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ABSTRACT

There are several conflicting trends in the rapidly changing transportation market, which are impacting transit ridership is varying ways. Transportation Network Companies have the potential to reduce or replace the need for auto ownership and may serve some populations better than transitional transit services, but limited survey research indicates that they may be adding more trips than they reduce. With recent surges in technology that negate the need for trips, low gas prices and a strong economy, and shifting populations, fixed route transit ridership is on the decline. However, research on all of these factors is limited and largely inconclusive. While it is useful to track ridership trends at the national level on a city-by-city basis, such analysis only yields limited insight.

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1.0 INTRODUCTION

New technologies have enabled novel mobility services that provide individuals with additional on-demand travel alternatives (ridehailing/ridesourcing). Customers typically use a smartphone to request a trip, pay the fare, track the progress of the vehicle, and rate the service. Transportation Network Companies (TNCs) such as Uber and Lyft, have updated traditional travel alternatives, but many provide better services than traditional options. The impact of new mobility services on traditional transit has been the subject of much speculation. Some see these new services as competitors that simply skim choice riders from the transit system, while others believe that offering as many mobility options as possible enables individuals to choose a car-free or car-lite life. There are many opportunities where public transit and technology-enabled transportation service providers can work together - services can fill transit service gaps, serve last mile connections, be more cost-effective for serving seniors and those with disabilities, and provide support during emergencies. Understanding why customers choose these mobility options can help provide first-hand information about the pros and cons of these services. Gathering information about the kind of trips these individuals make can further provide insight into the relationship between these services and traditional transit.

The initial objective of this study was to analyze the changes in transit ridership in the United States with the introduction of on-demand ridesourcing options, also known as Transportation Network Companies (TNCs). The first phase will include five tasks, including a literature and news article review, a transit ridership analysis, two tasks related to assessments of partnerships between TNCs and transit agencies, and final reporting. During the initial phase of the study, several ridership analyses similar to that proposed in the scope were published. Therefore, one task of the study pivoted to establishing peer groups for transit agencies to better understand ridership changes taking place. Additional work in understanding the impact of TNCs and other factors on transit ridership was begun and will be completed under year 2.

Additional tasks on TNC and transit relationships were completed focused on paratransit services and the technology company TransLoc. Traditional paratransit services are costly for operators to provide and users face costs above standard transit fares, lengthy travel times, and difficulties with real-time scheduling. This project assessed the structure of partnerships between shared mobility providers and the public sector to provide access to those with limited mobility. Further work in year 2 will relate more to the structure of the partnerships and cooperative agreements related to all transit services, especially first-mile/last-mile service gaps.

This report, therefore, begins with a comprehensive literature review in Chapter 2. Remaining chapters (Chapter 3 to 6) summarize the work described in the tasks above. This includes development of transit agency peer groups using cluster analysis, analysis of ridership change in three cities, an analysis of healthcare transportation services under the influence of Shared Mobility, and the future of Shared Mobility technology.

2.0   REVIEW OF LITERATURE

The Fourth Quarter 2016 APTA ridership report showed an overall decline of 2.30% in passenger boardings for the year and 4.29% for that quarter. In 2017, following five years of consecutive decline, bus ridership attained its lowest point since at least 1990, which is the oldest ridership data available from APTA. Even heavy rail declined following an upward trend since 2009. There are many possible factors for this decline in ridership. A recent APTA report identified erosion of time competitiveness, reduced affinity, erosion of cost competitiveness, and external factors as major trends in transit ridership (APTA 2018). While these trends are clearly happening, transit agencies need to understand the problem more specifically to address the underlying causes of transit ridership. This chapter contains a review of the literature on the factors found to affect ridership in recent years. While this review provides important leads, the literature has not yet painted a full picture of the forces pulling transit ridership downwards.

Despite some trends that were temporarily going in the opposite direction, suburbs have outpaced urban cores in growth rate (Frey 2018). At the same time, many trip purposes are disappearing. According to a 2016 Gallup poll, 43% of Americans reported working remotely at least sometimes, a 4-percentage point increase since 2012 (Gallup 2017). Telecommuters also reported working remotely more often; 75% reported working from home more than once a week from 66% in 2012. Additionally, delivery services such as Amazon and GrubHub have made shopping and dining delivery possible (Suel et al. 2018). However, total vehicle miles traveled are now at their highest point in history (Davis 2017). Therefore, understanding why these recent declines in ridership are occurring and what actions the transit industry should be taking to combat them is a complex problem worthy of further investigation in a timely manner.

Many in the industry are quick to blame these declines on Transportation Network Companies (TNCs) such as Uber and Lyft, which have used real-time and location-aware capabilities of smartphones to provide on-demand and/or tailored travel options to customers. These ride-hailing services have put dispatching and cashless payment options in the hands of the riders, proving strong competition to traditional transit services. Others believe that the decreases in transit ridership are due in part to the increases in bicycling and walking as modes of transportation with bikeshare programs claiming much of the decrease in transit ridership.

In an attempt to turn the declining ridership trend around, transit agencies have implemented new strategies. New fare technologies are helping to reduce the friction in transit fare purchasing. Transit agencies are also redesigning their bus network to increase frequencies on their core routes and attract new riders. Transit agencies are implementing micro-transit pilots to provide a similar experience to TNCs. This review summarizes the literature on causes of transit ridership decline, including social, economic, and demographic factors as well as the impact of emerging mobility services. Finally, strategies to increase transit ridership are reviewed.

2.1   TRADITIONAL CAUSES OF TRANSIT RIDERSHIP INCREASE AND DECLINES

Many factors affecting transit ridership are well established within the literature, and well summarized in Taylor and Camille (2003). Transit ridership is cyclical in nature and is substantially impacted by the economy and population changes, such as residential location choices. The level of employment has a mixed effect on ridership, while greater employment generates more trips from commuting and consuming, they also lead to private vehicle purchase (Hendrickson 1986; Liu 1993). The overall effect of employment, however, has been found to be positive overall (Gomez-Ibanez 1996). While gas prices have been found to have little impact on transit ridership, parking availability is an important determinant (Sale 1976; Dueker 1998). Transit ridership is highly correlated to housing and workplace density, although this variable has a relationship with many other ridership factors (Pushkarev and Zupan 1977; Spillar and Rutherford 1998; TCRP Report 95 2004). Although sensitivity to fare can vary widely within the customer base, modest changes in fares have been found to greatly affect ridership (Liu 1993; Kohn 2000). Finally, vehicle revenue miles and hours have been found to strongly correlate with ridership in multiple studies (Liu 1993; Gomez-Ibanez 1996; Kohn 2000; TCRP Report 95 2004).

2.2   FACTORS IMPACTING RECENT CHANGES IN TRANSIT RIDERSHIP

In summary, public transit ridership is affected by traditional economic factors, such as population and employment change (recession, gentrification, residential location), gas prices, and auto ownership. Transit ridership is also impacted by the amount of service being provided (frequency, coverage, span, availability), the cost of service (fares), and the quality of that service (speed, reliability, comfort). Although competition from other modes has always been prevalent, new modes such as TNCs, bikeshare, and carshare, are providing new options for travelers and new competition for transit. Furthermore, changes to how people travel are impacting ridership as well. Telework, flex work schedules, and online shopping are becoming more prevalent and impacting the demand for travel or the times we do it. In addition to shared mobility, three of the major factors impacting transit ridership are described below: demographic shifts, workplace policies, and service levels.

2.2.1 Demographic Shifts

Income, age, and race demographics are strongly correlated with car ownership, which is one of the main determinants of mode choice. Taylor et al. (2009) found that the population of recent immigrants and the percent of carless households were positively correlated with transit ridership. The correlation between demographic characteristics and transit ridership remains strong even when taking population density and access to transit into consideration. Owen and Levin (2015) predicted mode share based on accessibility measures and on demographics using data from the Minneapolis-Saint Paul Metropolitan Area at the census block-group level. They found that transit mode was negatively correlated with income and vehicle ownership, even when considering accessibility. Driscoll et al. (2018) modeled the impact of population age on transit ridership since 1989. They found that a contributing factor to the decline in ridership per capita was an aging population that makes fewer trips on average. In addition,

the authors point to slower rates of population growth in U.S. counties with abundant transit service than in counties with little transit available.

A potential contributing factor to the decreasing transit ridership is, therefore, the economic displacement of low-income earners from dense urban-centers to the suburbs. In his book, *The New Urban Crisis*, Richard Florida describes the phenomenon of gentrification taking place in major American metropolitan areas (Florida 2017). While cities are becoming denser, their populations are becoming whiter, have higher incomes, and more cars. A study from TriMet staff in Portland, OR, identified low-income migration as a major factor of transit ridership decline (Mills and Steele 2017). The study compared bus stop-level changes in the real-estate values with ridership changes and found a significant overlap. These preliminary results suggest that focusing service entirely on highest-density areas may not yield the maximum ridership.

In a 2018 report for the Southern California Association of Governments, increasing auto ownership especially among lower-income households was found to have a significant effect on falling transit ridership in the Southern California region (Manville et al. 2018). The region, despite heavy investments in transit infrastructure and service levels over the last 30 years, saw some of the largest drops in ridership, nearly 72 million annual trips, between 2012 and 2016. The study claims that most of the regions' ridership comes from a small proportion of people and neighborhoods, and despite investigating fares, fuel prices, TNCs, and displacement, vehicle ownership was found to play a dominating role in ridership drops according to their model. These findings are largely limited to the Southern California region, which may vary from the rest of the country in a variety of key factors surrounding vehicle ownership and use.

2.2.2 Workplace Policies

Workplace policies have evolved in ways that may affect fare purchases and transit ridership. The proportion of the population working from home has increased by 10% in the last decade. This trend may affect commuters' decisions to purchase monthly passes in favor of more flexible options. A study from Habib (2017) indicates that owning a transit pass correlates negatively with high-frequency telecommuting. The study, however, focused solely on post-secondary students in Toronto. More research on this phenomenon is needed to help transit agencies develop fare policies that support ridership.

Workplace policies have also been shown to alter employees' commuting habits in more general ways. A 2017 study by Bueno et al. used a multinomial logit model to show that parking and driver mileage benefits correlated with decreased transit use, while transit benefits and discounted passes correlated with higher transit use. This study was limited to New York and New Jersey, states with historically high transit use per capita. Similar research was conducted by Dong et al. (2016) in Portland, OR, and Block-Schachter and Attanucci (2008) in Boston, both with similar results. There is limited research on transit benefit programs in small urban areas with a lower transit mode share.

2.2.3 Service Levels

There is a consensus in the literature that the primordial factor for transit ridership is the service levels. In a simple one-variable regression of 265 urban areas, Taylor et al. (2009) found that vehicle revenue hours explained 95% of the variation in ridership. Dill et al. (2013) used bus stop-level data to model the determinants of transit ridership in three metropolitan regions in Oregon: Portland, Eugene, and Rogue Valley. They found that level of service characteristics were the most important factors to determine ridership. In Portland, where levels of service characteristics explained 41% of the variance in ridership, each extra minute of headway was associated with a four to five percent drop in ridership.

Service levels are not just good prediction variables for modeling transit ridership; their fluctuation also affects changes in ridership over time. In a 1988 time-series study, Kyte et al. (1988) compared transit ridership over several operators in the region of Portland, OR, before and after service changes. They found that ridership elasticity to service hours varied considerably among routes, but that the average significant elasticity was 1.34. Kain and Liu (1999) evaluated the factor that contributed to increasing ridership in Houston and San Diego in the late 1990s, while transit ridership was declining across the United States. The authors concluded that the increases in service, reduction in fare, and growth in employment and population contributed the most to increasing ridership. More recently, a study by Boisjoly et al. identified Vehicle Revenue Kilometers as the primary determinant of ridership in a panel regression study of 25 transit agencies from 2002 to 2015.

2.3   RIDERSHIP EFFECTS OF SHARED MOBILITY

The impact of new mobility services on traditional transit has been the subject of much speculation. Some see these new services as competitors that simply skim choice riders from the transit system, while others believe that offering as many mobility options as possible enables individuals to choose a car-free or car-lite life. There are many opportunities where public transit and technology-enabled transportation service providers can work together - services can fill transit service gaps, serve last mile connections, be more cost-effective for serving seniors and those with disabilities, and provide support during emergencies. Understanding why customers choose these mobility options can help provide first-hand information about the pros and cons of these services. Gathering information about the kind of trips these individuals make can further provide insight into the relationship between these services and traditional transit.

Two recent papers have studied the relationship between TNCs and transit using regression models. A large study on transit ridership by Boisjoly et al. (2018) used data from the 25 largest transit agencies in North America. The study measured the presence of Uber as a binary variable using the opening dates from a review of press releases. This study found that the presence of Uber did not have a statistically significant correlation with increased ridership. Most of the variation in ridership comes from the amount of service provided by each agency. A study by Hall et al. (2018) employed a difference in differences regression to evaluate the relationship between Uber presence and transit ridership. In addition to the binary presence of Uber in an MSA, the study measured the intensity of search engine searches using Google Trends. The study found that Uber presence and intensity correlated with

ridership decrease in MSAs with smaller population sizes and ridership increase in MSAs with large population sizes.

In a Center for Urban Transportation Research report (2016), Steve Polzin outlines policies for public transportation with regard to TNCs (and automated vehicles). He advises that agencies monitor the impact of technology on travel behavior, redefine transit's role as mobility options change, and position transit to address emerging issues. He specifically addresses the possibility of evolving paratransit and affordable mobility.

A Transit Center report published in early 2016 suggested that transit agencies partner with TNCs to create efficiencies in how service is provided by replacing inefficient markets and reallocating services (Transit Center 2016). They also suggested that transit agencies prompt TNCs to exchange data to understand rider needs better and many agencies have been following this advice. The result of this agency push to exchange data resulted in Uber opening up some usage data for analysts to begin to dissect.

In a chapter of Meyer and Shaheen's Disrupting Mobility, Henao and Marshall (2017) explain the complexities of understanding the impact of TNCs on the transportation system. First, the amount of open data to understand how TNCs are used is limited. Second, it is difficult to assess if a TNC trip is a replacement transit trip or not. Even if a particular trip takes place with a TNC, it may enable a household to own one less car and encourage more usage of transit in general. They employ modality styles (car, multimodal with car, non-car, and bi-style) to classify travelers.

One study conducted in Boston, Chicago, New York, Seattle, and Washington DC used a targeted email survey to understand TNC usage (Clewlow 2016). The surveys had 2,100 respondents in both urban and suburban transit-served neighborhoods with 426 respondents stating they were carsharing members (20%) and 674 who had used ridehailing (32%). In comparing the two major TNCs, the study found that the Uber market was much stronger with 90-97% of adopters having used Uber as opposed to 22-31% having used Lyft. A study from the San Francisco County Transportation Authority found that TNC trips are concentrated during peak hours and in the densest parts of the city (SFCTA 2017). The study also found that TNCs contribute 6.5% of all VMTs in San Francisco.

Another study conducted by Clewlow and Mishra (2017) used an internet survey to target a wider range of neighborhoods and suburban areas in Boston, Chicago, Los Angeles, New York, San Francisco, Seattle, and Washington DC. The survey collected information on attitudes towards travel, neighborhood, technology, and environment, as well as vehicle ownership and housing choice, and had nearly 4,100 respondents from a wide variety of population and housing densities both urban and suburban. They found that adopters of TNCs reduced their bus usage by 6% but increased their commuter rail usage by 3% on average, and 22% of respondents reported making a trip with a TNC that they would not have made without it, indicating a rise in overall trips due to TNCs.

Another study conducted in San Francisco used an intercept survey of taxi and ridesourcing customers (Rayle et al. 2016). They found that 33% of rideshare users would have made the trip by transit, 39% by taxi and only 6% would have driven their own car. Comparisons of trip origins and destinations showed

that ridesourcing users saved 10 minutes on average with a 22-minute average trip, although some trips would have been shorter on transit. However, the study was conducted among ridesourcing and taxi riders, which would presumably include more people for whom the transit trip was not the best choice.

The most comprehensive work to date on the subject is the Transit Cooperative Research Project (TCRP) Report 188 (Feigon and Murphy 2016). The study draws on interviews with transportation agencies; a survey of shared mobility users; travel time, demand, and capacity analysis; an assessment of paratransit practices and regulations; and documentation of business models. "The report presents five key findings:

1. Among survey respondents, greater use of shared modes is associated with greater likelihood to use transit frequently, own fewer cars, and have reduced transportation spending;
2. Shared modes largely complement public transit, enhancing urban mobility;
3. Because shared modes are expected to continue growing in significance, public entities should identify opportunities to engage with them to ensure that benefits are widely and equitably shared;
4. The public sector and private mobility operators are eager to collaborate to improve paratransit using emerging approaches and technology; and
5. A number of business models are emerging that include new forms of public-private partnership for provision of mobility and related information services." (pg. 6)

In the TCRP study, respondents reported that ridesourcing was used for recreation or social events the most (54%), followed by commute (21%), and shopping / errand (16%). Ridesourcing was the least preferred mode in the early AM, AM rush, and midday, but the most preferred mode in the evening and late night. In the survey, 43% of respondents reported using public transit more since shared modes became available, but 28% reported using public transit less. Of the respondents, 20% postponed buying a car, 18% decided not to buy a car, and 21% sold and did not replace a car since starting to use shared modes. However, the survey results were a convenience sample and therefore cannot be applied to the larger population. The survey also took place only in very large, dense cities including Austin, Boston, Chicago, Los Angeles, San Francisco, Seattle, Washington, D.C., and New York.

Agencies interviewed for the study expressed a strong desire to form partnerships with ridesourcing companies to bring down the cost of paratransit trips. Several hurdles were identified, however, including drug and alcohol testing of drivers, liability associated with transferring of non-ambulatory passengers, provision of door-to-door rather than curb-to-curb, wheelchair and service animal accommodations, vehicle safety and insurance requirements. Two additional papers found were duplicative of the efforts reported in TCRP Report 188 (Iacobucci et al. 2017; Shared Use Mobility Center 2016).

A FiveThirtyEight article looked into the relationship between transit and TNC usage, and cost factors for households with varying levels of transit service (Silver and Fischer-Baum 2015). Uber usage appeared to correspond well to transit usage in New York City, and neighborhoods with no subway access had significantly fewer Uber trips than those with even one line, suggesting a link between the two. The

authors examined cost of vehicle ownership and determined that middle-income groups with at least moderate transit access would save money by relying on a transit-TNC combination. The article did not discuss its methodology or sample size, limiting its authority.

Despite limited research on TNC's relationship to transit ridership, several studies have looked at taxis' effect on transit demand and ridership. Taxis' impact on transit may be similar to that of TNCs, as they both provide an on-demand mobility service with high demand. Nearly all taxi studies involve New York City taxi data, due to its accessibility and scale. One study by Yang and Gonzales (2014) created a model for estimating taxi demand in New York City based on 147 million taxi trips and the control of several factors. Among them was transit access time (TAT), a measure of access adding the walking time to the nearest station to the expected waiting time, which is calculated as half the scheduled headway. The study found that the increase of TAT by one minute correlated with a reduction in 36 taxi trips, and as TAT improved, taxi trips rose, indicating a connection between the two. Despite controlling for employment and population density, the authors admitted that some connection may be skewed by the disproportionate amount of taxis and subway lines in lower Manhattan.

A similar study by Wang and Ross (2016) explored the transit-competing and transit-complementing effects of taxis in New York City. Trips from a seven-day sample were categorized as transit extending if they began or ended at a transit station and ran outside of a transit-served area, transit complementing if they served as a substitute for a transit service that was nonexistent or not running at the time, and transit competing if the same route could have been achieved using transit. Binary logit models were run to determine trip types and link them with sociodemographic and built environment factors. The study found that 48% of trips were transit competing, 44.4% were transit complementing, and 7.4% were transit extending. The authors concluded that around half of the trips replaced transit trips while the other half complemented transit services. A study in Boston, MA, performed a similar analysis to investigate taxis' competing or complementing elements (Austin and Zegras 2012). The study showed that heavy rail stations generated fewer trips than surrounding areas, but that the opposite was true for light rail and BRT services.

Another study in New York City ran utility models on taxi and transit trips between New York area airports and Pennsylvania Station (Yang et al. 2014). A binary logit model was used to select mode choice based on utility functions, cost, and travel time valuation. Cost prohibited the utility of taxi trips for all times of day except overnight, when transit service frequency dropped significantly. Transit was most valuable during peak periods, when headways were shortest and vehicular traffic was highest. This study was limited by its evaluation only of New York City, where transit options are abundant and frequent, and where roadway traffic is high.

Studies on the impact of other forms of shared mobility on transit, including more established forms such as carsharing, have been conducted with mixed results. Households that utilize carsharing have been shown to use transit less than before joining carsharing (Martin and Shaheen 2011), and zero-car households that utilize carsharing have been shown to use transit less than zero-car households in general (Sioui et al. 2012). A study combining 15 reports, however, described carsharing members' transit usage increase between 13.5 to 54% after joining carsharing (Shaheen, Cohen, and Chung 2009).

Variabilities in these reports' results indicate that carsharing members' transit usage varies widely by region and that the rapidly changing landscape of transportation options has an unpredictable effect on mode choice.

On the whole, research in the area of transit partnerships with TNCs and the impacts of TNCs on transit ridership is severely limited due to the recent emergence of the services. Survey studies such as Clewlow (2017) help understand the attitudes of transit riders through stated preference. Regression studies such as Hall et al. (2018) and Boisjoly et al. (2018) help establish the connection between the presence of TNCs of transit ridership. However, neither approach has managed to establish clear trends. There needs to be a study of revealed preference on wide and representative scale in order to observe the full effects of TNCs on transit ridership. However, there is a consensus: understanding the competition and complementarity between transit and TNCs is among the most pressing research needs.

2.4   STRATEGIES TO INCREASE TRANSIT RIDERSHIP

This, therefore, begs the question of how agencies should address these factors, including modifying service to accommodate changes in the transportation system. Strategies can be operational in nature, such as route and network restructuring. They can be technological, such as new fare technologies or real-time information. They can involve new service types, such as demand-responsive transit. They can even involve new communication and marketing campaigns. Some strategies are discussed below.

2.4.1 Fare and Real-time Information Technologies

Recent technological advancements in fare payment technology are making it easier for passengers to use and pay for transit. Two emerging technological trends are occurring simultaneously: app-based smartcard payment systems such as Chicago's Ventra, and Near Field Communication (NFC) payment systems that do not require a transit pass at all as in Salt Lake City. These systems are flexible and save passenger time by avoiding the lengthy process of purchasing physical fare media. Due to the recent emergence of mobile-payment technologies, there still lacks research on their impact on transit ridership. A study by Brakewood, Macfarlane, and Watkins (2015) examined bus ridership changes in New York City in response to the gradual availability of real-time bus information. The study revealed a median ridership increase of 2.3%, with higher increases on the largest routes.

2.4.2 Bus Network Restructuring

Many recent service-related efforts to increase transit ridership have consisted in restructuring bus networks to prioritize service concentration over coverage. In August 2015, Houston's Metropolitan Transit Authority of Harris County redesigned their bus network overnight, increasing high-frequency bus routes, while cutting lower-frequency routes. Omaha Metro Area Transit, Austin's Capital Metro, and Columbus' Central Ohio Transit Authority (COTA) followed suit with their own network redesigns. Seattle's King County Metro went through a similar process albeit over several years (King County Metro 2017). Metropolitan Atlanta Rapid Transit Authority (MARTA) commissioned a Comprehensive Operations Analysis study, which also recommended concentrating service on core corridors (Parsons

Brinckerhoff 2016). In reducing their coverage, however, MARTA has faced stiff resistance from residents who rely on bus service as their only mode of transportation (Abubey 2017).

Called the "hottest trend in transit" by Governing Mag at the end of 2017, bus network restructuring is being considered by transit agencies across the nation. The Los Angeles Metro announced in May 2017 the start of a three-year process to restructure the bus network in response to a 20% drop in ridership over three years (Hymon 2017). The Dallas Area Rapid Transit (Schmitt 2017), the Southeastern Pennsylvania Transit Authority (Laughlin 2017), and the Washington Metro Area Transit Authority (Powers 2017) are planning similar bus network redesigns. Transit agencies are hoping that concentrating service on core corridors will help increase transit ridership. This expectation is supported by the positive results bus network redesigns have received so far. In November 2017, Streetsblog USA wrote that "Transit ridership is falling everywhere – but not in cities that redesigned their bus networks" (Schmitt 2017).

One potential contributing factor, which has not been addressed in the literature or in the press, is that these bus network redesigns were accompanied by net increases in bus operating budgets. In Houston, bus ridership increased by only 1.2% in the first year, which was much lower than the 20% expected, even though the operating budget increased by 4% (Vock 2017). In Seattle, bus ridership increased by 0.4% between 2014 and 2016, during which King County Metro redesigned their bus network (Small 2017). During the same period, the transit agency also increased bus-operating budget by 15% and implemented bus prioritization treatments. In Austin, the ridership increase is also partly attributed to night and weekend bus service expansions (Pritchard 2017).

There is a need for research to parse the contributing factors of ridership and evaluate the singular impact of prioritizing concentration over coverage. A key element that needs to be understood is the notion of access. Low-frequency transit routes can be used as access modes to feed into high-frequency routes. The ridership on high-frequency routes should, therefore, be categorized by access mode to fully understand the dynamics of ridership and the impact of bus network redesigns.

2.4.3 Implementing Demand-Responsive Transit

To provide greater transit access in low-density neighborhoods, a new strategy consists of using demand-responsive transit. Research has shown that in low-density areas, demand-responsive transit can service short trips faster (Qiu et al. 2015) and at a lower cost than fixed routes (Edwards and Watkins 2013). Several transit agencies have implemented demand-responsive service either to reach the first-and-last-mile or to connect origins and destinations directly.

There are two main approaches used in practice to provide demand-responsive transit. The first approach consists in using third-party software to dispatch agency operators. The Denver Regional Transit Authority has been providing dynamic rides with their own vehicles and operators since 2000 (Becker et al. 2013). The Kansas City Area Transportation Authority and Santa Clara Valley Transportation Authority both offered demand-responsive transit programs operated by their own staff, but the programs were discontinued due to insufficient ridership (Westervelt et al. 2018). Austin implemented a similar program and reached six-month ridership goals within two months (Bliss 2017).

The second approach consists in employing independent drivers who use their own vehicles to pick-up customers at their door. Pinellas Suncoast Transit Authority was the first transit agency to subsidize a portion of Uber, Lyft, and taxi trips to and from their bus stops. The Los Angeles Metro is planning a similar program in partnership with the technology company, VIA. The advantage of going through independent drivers is that the transit agency can take advantage of economies of scale from existing networks of ride-hailing drivers. There still lacks, however, quantitative research to assess the service and ridership implications of the programs.

2.4.4 Communication and Marketing

To increase the visibility of transit service, agencies are also looking to improve communication and marketing. Transit marketing has traditionally been eligible for the federal Congestion Mitigation and Air Quality programs in regions that are not attaining air-quality standards. For example, the Atlanta Regional Commission used the funds for a social media campaign to convince people to try transit. In the book, *Best Practices for Transportation Agency Use of Social Media (2013)*, Bregman and Watkins describe potential strategies for transit agencies to create an online presence. While the impact of marketing campaigns on transit ridership has been mixed, research has shown that targeted campaigns, especially for expanded service are most effective (TCRP Report 95 2004). Van Lierop and El-Geneidy (2017) developed a conceptual framework to segment the market for marketing efforts.

2.5 CONCLUSIONS

There are several conflicting trends in the rapidly changing transportation market, and public transit may be falling behind. TNCs have the potential to reduce or replace the need for auto ownership, but limited survey research indicates that they may be adding more trips than they reduce. Uber has been shown to complement transit and even correlate with improved ridership, but research is limited both in data availability and scope of cities studied. Recent surges in technology that negates the need for trips, including Amazon, Grubhub, and the ability to work from home may also allow former transit riders to forgo their monthly passes and traditional commitment to riding transit. Low gas prices and a strong economy, both correlated with higher amounts of driving, are perhaps playing a role as well. Research on all of these recent trends is limited.

In addition, shifting populations within metropolitan regions may also play a role in the recent decline in transit ridership. Gentrification has the potential to displace transit-dependent groups with populations more likely to drive, and trends such as the suburbanization of poverty make auto ownership even more likely for groups formerly likely to be regular transit users. Aging populations in cities may also be less likely to take transit. However, research on all of these factors is limited and largely inconclusive. Transit agencies' strategies involving fare technology and marketing are so far inconclusive. Demand-responsive, 'microtransit' pilots and network restructuring may be working to combat declines in ridership, but may also come with additional service that plays a larger role than has been acknowledged. Ultimately, the most conclusive evidence for maintaining and improving ridership remains an agency simply providing more service to its customers.

3.0   COMPARING TRANSIT AGENCY PEER GROUPS USING CLUSTER ANALYSIS

Research conducted by Dr. Kari Watkins, Dave Ederer, Dr. Simon Berrebi and Chandler Diffee, Georgia Institute of Technology. The full paper will appear in Transportation Research Record in 2019 (See Appendix A).

3.1   INTRODUCTION

Transit ridership has decreased steadily each year from 2014 to 2017 despite increasing urban populations and transit service investment. Transit ridership in the United States has declined each year since 2014. Bus ridership, in particular, has dropped substantially with a 4.27% decrease in unlinked passenger trips in 2017 compared to 2016 (Hughes-Cromwick and Dickens 2018). There are likely many reasons for changing ridership. Automobile ownership, parking availability, cheap fuel, ride-hailing services, poor network coverage, and low-frequency service have been cited as causing decreased ridership (Boisjoly et al. 2018; Brown and Neog 2012; Taylor and Fink 2013; Taylor et al. 2009). These analyses have examined trends in national transit ridership levels or within specific agencies or regions. However, the magnitude and causes of ridership changes are likely to vary from place to place (Brown and Neog 2012). Thus, comparing transit agencies and the areas they operate in to similar peers may yield more informative results than examining national trends or only amongst large agencies. There is a wide range of transit agencies that serve different populations, operate different services, and have drastically different budgets. These and many other factors are likely to substantially affect operations and ridership.

Ridership is influenced by factors that are both controlled by and external to an agency's actions. For example, agencies can control service frequency, but have little influence over population density in a service area. Factors outside of transit agencies control that are related to ridership include population size, density of persons or businesses, presence of high number of college students, and percentage of zero vehicle households (Taylor et al. 2009). Even operating expenses, which are typically considered as an internal factor, are by and large outside of agencies' control. These factors, which are structurally related to transit ridership but outside of agencies' control, provide a framework to cluster metropolitan regions in groups of peers. This framework captures the main dynamics affecting regions that share common characteristics and can allow us to better understand the sub-trends that make specific regions stand out compared to their peers.

In this research, we group metropolitan areas that operate transit service into groups on a set of variables that affect ridership but are outside of agencies' control: total population, density, percent of zero vehicle households, and transit agency operating expenditures. Using Ward's method, metropolitan regions will be clustered by mode family, separating mixed and dedicated right-of-way. Using this categorization, ridership trends can be analyzed in a more meaningful way.

3.2   LITERATURE REVIEW

The factors that predict transit ridership have long been the subject of speculation and study. Many studies suggest that service levels are the most important variable related to transit ridership. Service levels are typically measured in vehicle revenue miles (VRM) or hours (VRH). In a simple one-variable regression of 265 urban areas, Taylor et al. (2009) found that VRH account for 95% of variation in ridership. In a bus stop-level analysis of three cities in Oregon, Dill et al. (2013) found that characteristics in service, most notably headways, were the most important factors to determine ridership. Other factors accounting for ridership variation include population density, auto ownership, and fares. In a panel regression of 25 North American regions, Boisjoly et al. (2018) found that auto ownership and vehicle revenue kilometers account for the most variation in transit ridership, and fares were significantly correlated with ridership. A panel study by B. Lee and Y. Lee (2014) found that gas prices had a higher effect on transit ridership in regions with higher density.

Much of the research cited in our review examines national trends or trends within specific agencies. It is likely that the factors that influence ridership differ from city to city. To properly compare transit agencies, a more accurate approach may be to delineate different groups of transit agencies identified as similar using a parsimonious set of covariates. Many agencies "benchmark" their performance against agencies that they consider similar to their own. Benchmarking is typically performed using data reported to the Federal Transit Administration's National Transit Database (NTD). The NTD is updated annually and contains information about ridership, budgets, and operations. Many agencies use the NTD to compare themselves to other agencies, but NTD data is organized in a manner that makes it difficult to compare within agencies from year-to-year, let alone across agencies (Gan et al. 2011). As a result, the Florida Department of Transportation created the Integrated National Transit Database Analysis System (INTDAS) to allow transit agencies to easily access and use NTD data available since 1984 (Gan et al. 2002). This program has grown over time to include peer grouping functions for small and large transit agencies (Parks et al. 2010). The system allows users to select 6-10 variables included in the final peer-grouping model, as well as three screening factors. TCRP 141 and the Integrated National Transit Database that resulted from it are the first attempts to create peer groups on a national scale (Parks et al. 2010). However, this system is intended for specific benchmarking purposes rather than analysis. Many of the variables included to benchmark are not necessarily relevant for research and analysis. In addition, the groupings vary depending on weights that are defined by the user. No fixed set of peer agencies currently exists.

Other researchers have attempted to create peer groups for the purposes of comparing agency performance. The National Center for Transit Research developed a method to create peer groups based first on geographic region, then demographic and operational characteristics (Perk and Kamp 2004). This effort was limited to bus service, however, and did not consider all agencies in the United States. An analysis by Brown and Neog splitting Metropolitan Statistical Areas (MSAs) into groups of smaller (500,000 to 1 million people) and larger MSAs (1-5 million people) found that changes in ridership were similar between the two groups. In both groups, service frequency, service coverage, and percent of households not owning an automobile were significantly related to transit ridership.

However, these effects were not observed when analyzing all MSAs together. Thus, comparing transit ridership amongst all agencies and MSAs may mask heterogeneous effects or suggest spurious correlations.

Although several methods have been developed to group peer agencies together for analysis of trends and benchmarking, a research gap still exists for analyzing transit services at the metropolitan level in order to analyze ridership trends.

3.3   METHODOLOGY

Analyzing transit ridership in metropolitan areas required manipulating census and NTD data to aggregate demographics and ridership at the metropolitan area level. The clusters were created on the following metrics:

- Metropolitan area population – American Community Survey
- Percent of population living in an area with density that supports transit - American Community Survey using the Federal Transit Administration's definition of transit supportive density of 3 or more housing units in an acre (Kittelson et al. 2013)
- Percent of zero vehicle households – American Community Survey
- Transit-agency operating expenses – National Transit Database

Several additional variables were considered and the process is explained further in Ederer et al. (2019). The four final variables selected have been shown to be related to transit ridership and are relatively stable over time (Taylor and Fink 2013; Taylor et al. 2009). Population and percent of population living in dense areas accounted for most of the variation within and between clusters in the analysis. However, percentage of zero vehicle households and operating expenditures for different modes provided key distinctions in some cases.

Two cluster analyses were completed: one for transit services in dedicated right-of-way as defined in the NTD, and one for services not operating in a dedicated right-of-way. Dedicated right-of-way services included the following modes: heavy rail, light rail, monorail, commuter rail, and hybrid rail. Dedicated right-of-way services included only those systems which have 1 million or more unlinked passenger trips each year. The second group included all metro areas operating intra-city bus, commuter bus, bus rapid transit, and streetcar service.

Ward's method of agglomerative hierarchical clustering was used to identify metropolitan areas with fixed characteristics that are similar in ways that are related to transit ridership. Ward's method was selected for this analysis because this method functions by minimizing the amount of intra-cluster variance and maximizing inter-cluster variance.

All values were scaled prior to running the cluster analyses in order to prevent metrics with large values from weighing more heavily on the cluster analysis. Other clustering methods were tested and the clusters were similar across methods. In all cluster solutions, the New York City metropolitan area was

not included in this analysis as the size of its transit network is orders of magnitude larger than other agencies in the United States.

3.4   RESULTS

Figure 1 below delineates the clusters for metropolitan areas operating dedicated right-of-way services with at least 1 million trips per year. Based on the scree plots, gap statistics, and interpretation, five clusters of metropolitan areas operating dedicated right-of-way services were selected.

Cluster 1 consisted of sprawling large metro areas with relatively few dense census tracts, many of which are located in the southern and western regions of the U.S. Most areas in this group had relatively similar levels of ridership and the least number of people living in densely populated areas. The second cluster consists of cities that are relatively small, compact, and with a high percentage of zero vehicle households. This includes former industrial hubs in Baltimore, Buffalo, Cleveland, and Pittsburgh. All four of these areas experienced their highest growth rates before the 1950s when compact urban development was the norm and have rapidly declined in population, industry, and economic activity since then. The third cluster includes Chicago, Boston, Philadelphia, San Francisco, and Washington, D.C. These are large metro areas with extensive transit systems and large commuter rail networks. Like the cities in Cluster 2, the Cluster 3 cities developed before the relatively newer cities in the south, and mountain west. Of all the clusters, these cities have the highest percentage of zero vehicle households and close to half the population living in dense areas.

Cluster 4 consists of medium-sized metro areas that are mainly in the western areas of the country. These cities have low percentages of zero vehicle households, but a high proportion of population living in dense census tracts. The transit systems in these areas tend to be relatively new and are growing quickly. Most of the systems contained in this cluster are light rail systems rather than the legacy heavy rail systems in Cluster 3. The Los Angeles metropolitan area was an outlier in this grouping. It is unusually large with a higher percentage of people in dense areas, but with very low investment in dedicated right-of-way service. It was thus included in Cluster 5 by itself.
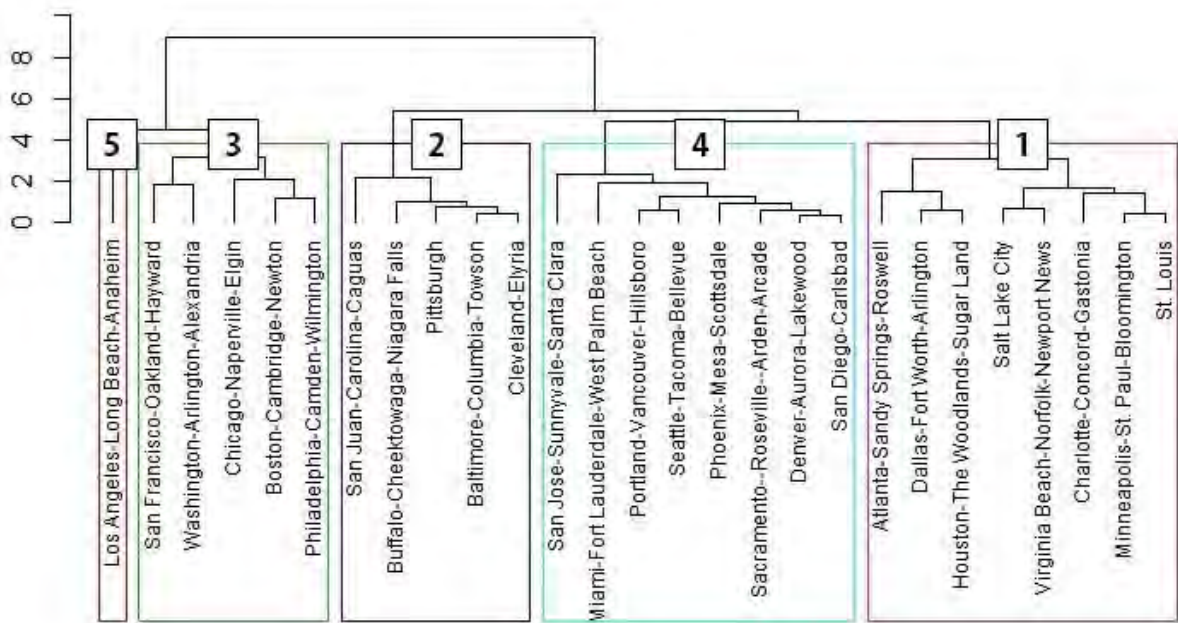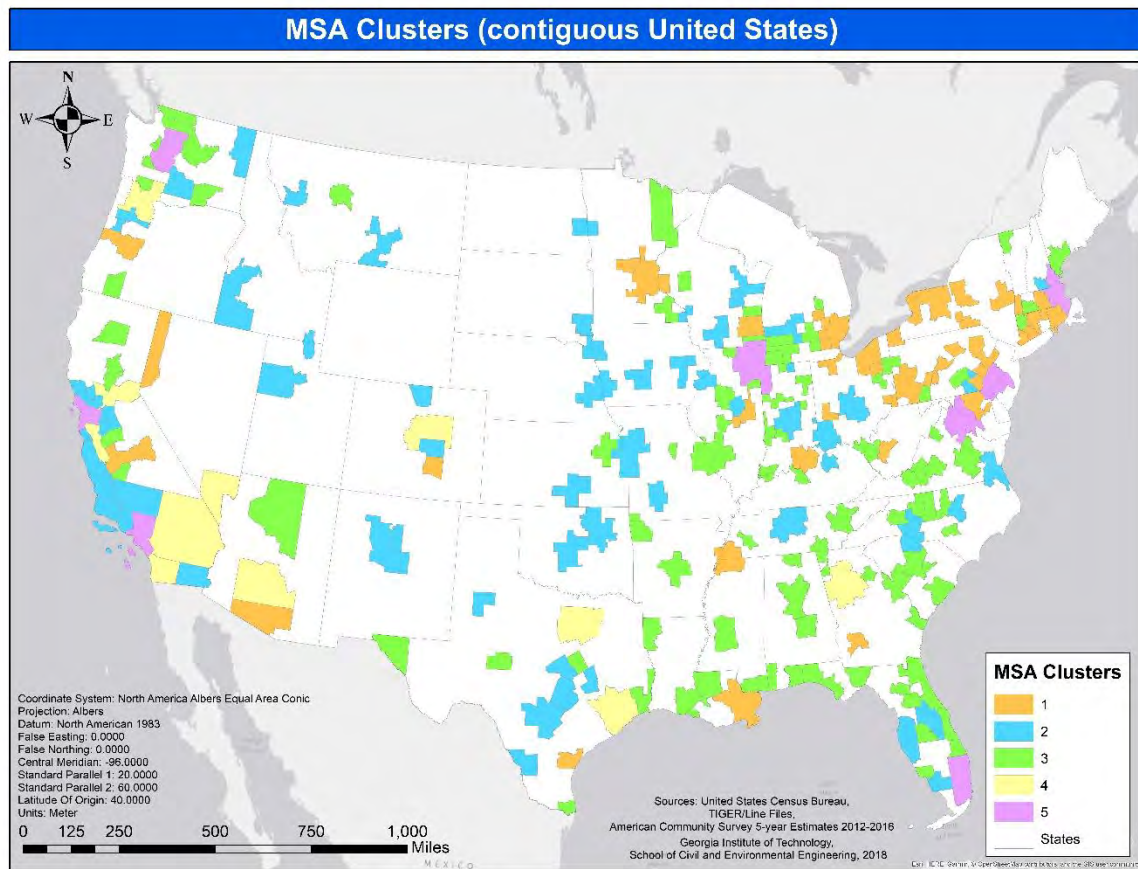
Figure 1. Dedicated Right-of-Way Cluster Dendrogram

Figure 2 visually displays the distribution of non-dedicated right-of-way agencies by cluster across the country. As with the dedicated right-of-way clusters, there are similarities within clusters that are related to geography and development patterns. Cluster 1 in this analysis is qualitatively similar to Cluster 2 in the dedicated right-of-way analysis and includes many of the same areas. It features older industrial cities that are typically in the Northeast and Midwest that have declined in population in the past several decades. These areas have a relatively high percentage of zero vehicle households and are typically small to mid-size metro areas. Cluster 2 primarily features small to mid-size, recently developed cities in the Midwest and South with low percentages of people living in zero vehicle households. However, these areas are similar to those in Cluster 1 in terms of percentage of dense population.

Figure 2. Metropolitan areas by mixed right-of-way cluster.

Cluster 3 consists of the smallest cities operating fixed route transit service in this analysis and includes a disproportionate number of "college towns." The metro areas in this cluster are the least dense, least populated, and spend the least on transit of the agencies included in this analysis. Ridership in this group reflects these numbers as this group has the lowest number of unlinked passenger trips. Cluster 4 is similar to Cluster 1 in the dedicated right-of-way analysis. The cities in Cluster 4 are sprawling, large cities that have a low percentage of zero vehicle households. No city in this cluster has fewer than 1.9 million people. Operating expenditures in this cluster reflect the large population of these areas.

Last, Cluster 5 consists of the largest metro areas in the county. These areas invest heavily in transit, are very dense compared to those areas in Clusters 1-3, but comparable to metros in Cluster 4. Unlike the dedicated right-of-way analysis, Los Angeles is included in Cluster 5 in this iteration. This is because Los Angeles area transit agencies invest in bus operations at a level more in line with the size and density of the metropolitan area. The regions in Cluster 5 spend substantially more on bus operations than regions in other clusters and subsequently have substantially higher ridership.

Trend analyses were conducted on both the mixed right-of-way and dedicated right-of-way clusters. These analyses show how the change in ridership relates to changes in factors that have been shown to be highly correlated with transit ridership in past studies (Boisjoy et al. 2018; Taylor et al. 2009). The initial results are presented in the full Transportation Research Record paper (Ederer et al. 2019). Additional work using these clusters to understand transit ridership change is ongoing through the Transit Cooperative Research Program J-11 Task 28 study.

3.5   CONCLUSIONS

Determining the causes of changes in transit ridership is critically important for operations and funding decisions for transit and transportation. Understanding trends will help agencies deliver better service and governments invest limited funding more effectively. While it is useful to track ridership trends at the national level or for a few of the largest agencies, such analysis only yields limited insight. With a parsimonious set of variables shown to influence transit ridership, it is possible to classify transit agencies into groups to analyze ridership trends. Rather than comparing a single transit agency against average performance metrics in the United States, it is more informative to compare trends within similar groups of agencies and metropolitan areas.

To date, research has not extensively analyzed ridership in groups classified on demographic and land use characteristics, but has been limited to examining trends at national and agency levels. This analysis applies to transit ridership at metropolitan rather than agency levels alone. While transportation agencies and funding typically follow jurisdictional lines, the land use demographics of metropolitan areas heavily influence transit ridership. Further, "service areas" are defined differently by every agency and may not reflect where riders are from. Examining the performance of transit ridership at the metropolitan level examines whether the needs of the population living in those areas are met. Use of these clusters in ridership analysis suggests that changes in ridership are not uniform across modes and clusters. Further information is available in Ederer et al. (2019) and the forthcoming TCRP report.

Finally, an indirect benefit to creating these clusters is that they can be used as peer groups for transit agencies to benchmark against one another. Benchmarking is a key component of strategic planning and process improvement. An analysis of small to mid-size U.S. transit agencies suggests that strategic planning and performance measurement contribute to improved performance metrics listed in the National Transit Database (Poister et al. 2013). This is especially difficult for smaller areas that may have limited staff capacity and resources to determine who their peers may be. Creating peer groups by clustering on relatively few variables assists in making the peer groups more intuitive and easy to understand for transit agencies.

4.0 UNDERSTANDING RIDERSHIP CHANGE IN PORTLAND, MIAMI, AND MINNEAPOLIS

Research conducted by Dr. Kari Watkins, Dr. Simon Berrebi, Taylor Gibbs and Sanskruti Joshi, Georgia Institute of Technology.

With an 11% nationwide decline in bus ridership between 2012 and 2017, understanding the intricate dynamics of ridership change is critical. Work being done by the project team through the STRIDE Center is evaluating the local dynamic of bus ridership in multiple cities. Although the research is ongoing in year 2, three cities – Portland, OR, Miami, FL, and Minneapolis-Saint Paul, MN – are presented briefly here with our initial results.

In this research, bus ridership is modeled at the stop-segment level (collection of 7-13 stops) over five years using data from Automatic Passenger Counters aboard the buses. We begin by analyzing the relationship between ridership and frequency of service. Isolating the effects of frequency, and using data on population and demographics, we identified the factors correlated to ridership in the base case. These factors and their change over time were then used to model ridership change. This analysis provides a description of bus ridership trends and their associated factors in agencies of similar sizes but widely different environments. The method and some of the results can be generalized to better understand this national phenomenon.

4.1 INTRODUCTION

American cities are experiencing an unprecedented crisis in bus ridership. In 2017, following five consecutive years of decline, bus ridership attained its lowest point since at least 1965 when the American Public Transportation Association started publishing the data (Cihak et al 1990; Dickens 2018). Bus ridership, which represents almost half of all transit trips, is driving down overall transit usage. While heavy rail, light rail, and commuter rail ridership did not start declining until 2014, their combined ridership has increased since 2012. Nonetheless, the 11% drop in bus unlinked passenger trips has caused overall transit ridership to fall by 4% in the same period. This trend is alarming for cities because the decline in transit usage is matched with an 8% increase in vehicle miles traveled nationwide (US DOT 2018). Therefore, lower-occupancy modes are compensating the drop, causing negative externalities including traffic congestion, pollution, obesity, and traffic fatalities. Furthermore, the lost fare revenue makes it more difficult for transit agencies to deliver service, which reduces access for parts of the population that have no other means of transportation.

Identifying causes in ridership decline is challenging because the geo-spatial dynamics are still misunderstood. In order to understand the causes of transit ridership decline, it is important to take into consideration the local dynamics taking place. Following the influx of affluent residents in urban cores since the early 2000s, rents have increased in cities across the United States (Edlund et al. 2015). In turn, low-income populations, who are the least likely to own private vehicles and the most likely to ride transit have migrated towards lower density neighborhoods where transit is less accessible (Kneebone

2017). At the same time, transit agencies have had to make difficult choices on how to allocate service. In the face of both ridership decline and population shifts, service allocation is the main lever for transit agencies to react. Transit networks change over time, whether by deliberate policy or sequential adjustments. Since population, demographics, and service levels are closely related to ridership and to each other, concurrent trends should be evaluated on a highly disaggregated spatial scale to fully capture the factors of ridership change.

Recent studies have measured ridership change with respect to land-use, demographics, and service levels at the national and regional levels (Taylor et al. 2009; Lyon et al. 2017; Boisjoly et al. 2018; Driscoll et al. 2017; Ederer et al. 2019). While these studies help identify the broad trends associated with transit ridership, they cannot distinguish underlying phenomena happening at a local level. Another study has evaluated ridership in Oregon cities at the stop level but at a single point in time (Dill et al. 2013). Although this study identifies the service, density, and demographic variables associated with ridership, it does not explain the change in ridership. Therefore, there lacks research on the factors associated with ridership change at a local level. Filling this gap is necessary for transit agencies to understand the environmental factors affecting ridership in their service areas, the impact of service allocation policies, and the type of actions they can take to reverse the downward ridership trend.

4.2   METHODOLOGY

This paper analyzes the change in transit ridership in three systems, TriMet in Portland, OR, Miami-Dade Transit in Miami, FL, and Metro Transit, in Minneapolis St-Paul. For each system, we used a fixed-effects model to explain the relative change in ridership. The fixed-effects model removes the idiosyncratic variation to focus solely on the relationship between change in ridership and change in explanatory factors. Therefore, to maintain a stable framework of comparison, we only considered constant stops, which are stops that were neither added nor removed during the entire study period. The study period was between 2012 and 2017 in Portland, OR, and Minneapolis/St Paul, MN, and from 2013 to 2017 in Miami, FL. We could not use the same study period for each system due to data restrictions.

We used multiple data sources to model ridership change on a hyper-local level. Automatic Passenger Count data, which have never been used for this type of analysis and on this scale, provided average weekday passenger boardings at the stop-level. Stop-level data were then aggregated into route-segments, defined as collections of 7 to 13 adjacent constant stops on the same route-direction combination. These data were explained with levels of service obtained from third party websites TransitFeeds and GTFS Data Exchange in the General Transit Feed Specification format. We also used population, jobs and demographic data within a 1/4 mi. from each bus stop from the Census Bureau's Longitudinal Employer-Household Dynamics.

4.3 RESULTS

In our model, the relative change in ridership at the stop-segment level is explained by the relative change in frequency, 2012/2013 productivity, population, jobs, demographic, and change thereof. The coefficient of determination (R^2) was 0.36 for Portland, 0.20 for Miami, and 0.40 for Minneapolis. For each of the three transit agencies the most relevant and significant results are summarized as follows:

- Ridership was elastic to frequency in Portland (coef = 1.55) and inelastic in Miami (coef = 0.76) and Minneapolis (coef = 0.61). However, this difference is most likely explained by the following factor.
- When interacting with the relative change in frequency with 2012/2013 frequency, Portland's coefficient was strongly negative (coef = -2.23E-2) and Minneapolis' was slightly positive (coef = 5.17E-3). In other words, ridership on frequent routes was less sensitive to change in frequency than the rest of the system in Portland, whereas the opposite was true in Minneapolis.
- In both Portland (coef = -10.19) and Minneapolis (coef = -22.03), 2012 productivity (boardings per trip) was negatively correlated with ridership change. In other words, the most productive routes lost the most ridership.
- While in Portland (coef = -1.29 and -2.27)) and Miami (coef = -0.23 and -0.20), the proportion of white and non-Hispanic residents was associated with ridership decline, the inverse is true in Minneapolis (coef = 0.60 and 1.87). In Portland (coef = -1.28), the proportion of low-income residents was associated with ridership loss. In Minneapolis (coef = 6.21), the proportion of residents who did not graduate from high school was associated with ridership gain.
- In all three systems, at least one demographic variable associated with gentrification helps explain ridership change. In Portland (coef = -1.60) and Miami (-0.41), an increase in the proportion of white residents was associated with ridership decline. In Minneapolis (coef = 2.98), an increase in proportion of residents who did not graduate from high school was associated with ridership increase. Note that these results are only significant at the 0.1, 0.05 and 0.1 level respectively.

4.4 CONCLUSIONS

The results from our model indicate both differences and similarities between the transit systems. The 2012 frequency had an inverse effect on the elasticity of ridership to frequency in Portland and Minneapolis. In other words, ridership is more elastic to frequency on infrequent routes in Portland and on frequent routes in Minneapolis. However, it is true in both systems that the most productive route-segments (in boardings per trip) lost the most ridership. The model also indicates that economic displacement of transit-dependent patrons may be causing ridership to decline in all three systems. Future research by our research team will extend this work by considering housing prices and ride-hailing usage. Adding these variables will help analyze the effects of demographic shifts and the competition/complementary of ride-hailing companies.

Additional findings will be presented in the STRIDE year 2 report for this study, as well as various publications by the study team.

5.0   HEALTHCARE TRANSPORTATION SERVICES: POLICY SHIFTS AND THE INFLUENCE OF SHARED MOBILITY

Research conducted by Dr. Noreen McDonald and Mary Wolfe, University of North Carolina. A full paper has been submitted for publication. A summary is presented below.

5.1   INTRODUCTION

Transportation barriers prevent millions of people from accessing healthcare every year. Estimates from 2005 suggest that 3.6 million Americans miss or delay nonemergency medical treatment annually despite having healthcare coverage due to lack of transportation to care facilities (Wallace et al. 2005). It is widely acknowledged that when patients have access to routine and preventative care, overall health outcomes are improved and costly ambulance bills or emergency department visits can be avoided. As the healthcare market moves towards value-based arrangements, treatment adherence is critical. At the same time, the U.S. has seen a proliferation and normalization of shared mobility technology in recent years. It is estimated that 24%-43% of the U.S. population uses some form of ridehailing service (Molla 2018). Ridehailing companies like Uber and Lyft have entered the market to capture a significant share of current spending on nonemergency healthcare transportation. Across the country, care providers are partnering with shared mobility services to establish new ways for patients to access on-demand rides to and from medical appointments. This nationwide scan examines the current landscape of these innovative healthcare mobility services. We first analyze the policy environment in which innovation is occurring. We then describe and catalog services by their key features and depict specific examples of hospitals, health systems, and paratransit providers who are leveraging ridehailing technology to improve service delivery of healthcare transportation.

5.2   METHODOLOGY

In this project, we ask: How is ridehailing technology changing healthcare transportation in the U.S.? We conducted a nationwide scan of periodicals, press releases, and academic sources (Google Scholar, Google News, and LexisNexis) to look for innovative healthcare mobility services. Specifically, we catalogued any instance since 2005 in which (i) a ridehailing company is facilitating healthcare transportation OR (ii) ridehailing technology is utilized to connect patients to trips in a vehicle for nonemergency medical purposes. We implemented a keyword-based search with a snowball-like sampling approach in which we pursued any reference within a source to an external instance of innovation beyond the source at hand. For each case of innovation identified, we abstracted key information including: key stakeholders, launch date, transportation provider, location/service area, who pays, booking method, target population, level of service, and any recorded benefits/outcomes. We used this information to create a typology of healthcare mobility services innovation.

5.3   FINDINGS

We discovered 53 cases of innovation in this scan. After analyzing key characteristics across these cases, we identified three core types of innovation or collaboration:

1) The first is when a healthcare provider leverages ridehailing technology to book patient trips. This was the most common type of innovation we found and it primarily involves transportation companies tailoring the ridehailing experience to the healthcare industry. The critical feature of this innovation is the added HIPPA-compliance of the booking process. Healthcare associates can order rides from new and existing ridehailing services through a HIPPA-compliant web platform; these centralized dashboards also allow providers to track patients' trips, record billing and spending information, and send patient reminders to a mobile or landline. Importantly, providers can schedule rides on behalf of patients even if they do not have a smartphone. An example of this innovation is Uber Health, which launched in March 2018.

2) The second type of innovation we identified is when an insurer partners with a ridehailing company. This is when a health plan or care delivery system formally partners with existing ridehailing service(s) to expand transportation services offered to beneficiaries or offer these services for the first time. While examples of this type were limited, it is likely that these types of partnerships will become more common as insurers increasingly offer more supplemental, non-medical benefits (a result of a larger shift of the healthcare industry to value-based care). This collaborative innovation reflects insurers' acknowledgement of transportation to care as a social determinant of health. An example on this category is when Blue Cross Blue Shield partnered with Lyft in May 2017 to add the ridehailing service for medical appointments to some company plans.

3) The third type of innovation is when a paratransit provider partners with a ridehailing company. Due to the demand-responsive nature of paratransit provisions (e.g. services do not operate over a fixed schedule like a standard public bus; rather, vehicles are dispatched on request and operate door-to-door), paratransit services have been said to be a sort of progenitor of mobile app-based Transportation Network Companies (TNCs). Sources that we located reference the increased flexibility and reliability of ridehailing services compared to traditional paratransit. In most cases we found transit agencies are subsidizing these trips while in a pilot phase, so long-term viability of these partnerships is unknown. A prominent example of this type of collaboration is led by the Massachusetts Bay Transportation Authority's Paratransit service called the RIDE. Since September 2016, the RIDE has been piloting a program with Lyft and Uber and the pilot has been extended several times.

5.4   CONCLUSIONS

In this scan, we encountered various avenues through which innovation in shared mobility is driving the evolution of healthcare transportation. Across the country, care providers are partnering with ridehailing services such as Uber and Lyft to establish new ways for patients to travel to and from medical appointments. We identified three main ways in which this is happening. Ridehailing options are being incorporated in electronic health record workflows of clinicians and they are becoming a part

of the choice set for patients through formal partnerships between ridehailing companies, healthcare providers, insurers, and transit agencies. The on-demand nature of rides and integration of ride requests and payment options appear to be the strongest drivers of these innovations. While new partnerships and companies continue to emerge in healthcare mobility services, it is important for both healthcare providers and transportation providers to evaluate programs to ensure that they are accessible to the most vulnerable patient populations. While many of the partnerships and companies encountered in the scan are implementing avenues of utilization outside of traditional smartphone apps (e.g. dial-in options from a landline), patient level of comfort with and perception of ridehailing is likely a very important determinant of uptake. Depending on patients' level of previous experience with ridehailing services, any TNC-based offering may be unfamiliar territory to the patient population it aims to serve.

6.0 THE FUTURE OF SHARED MOBILITY SYSTEM TECHNOLOGY

Research conducted by Dr. Billy Williams and Shoaib Samandar, North Carolina State University.

6.1 BACKGROUND

TransLōc was founded in 2004 by a small group of friends who had recently graduated from North Carolina State University's College of Computer Science. The leader of this group was Josh Whiton. Their initial aim was to provide transit users visual access to real-time bus location over the internet. In the early years, the fact that these entrepreneurs were not transit professionals by virtue of education or experience was a strength. They were transit users, and the company's early focus was solely on enhancing transit user experience. Early customers were dominated by university campus transit systems. As the company matured and expanded into business relationships with municipal and regional transit agencies, TransLōc's suite of products and services grew to include transit system management support, and the company adopted the mission of Making Transit the First Choice for All. In recognition of TransLōc's "incredibly positive and widespread impact on the way people think about and use public transit," Josh Whiton was selected in 2013 as one of ten White House *Champions of Change* honorees under that year's theme of *Transportation Technology Solutions for the 21st Century*.

In early 2018, TransLōc was acquired by Ford Smart Mobility LLC, a subsidiary of Ford Motor Company. As a member of the Ford Smart Mobility team, TransLōc continues to operate independently with its corporate headquarters remaining in Durham, NC, adjacent to the Research Triangle Park and its mission of Making Transit the First Choice for All unchanged. The information in this chapter is taken from: 1) the 2018 TransLōc document *Agency-Owned Microtransit: An Executive Guide*; 2) notes from a guest lecture that Josh Cohen, National Director of Policy, delivered to an North Carolina State University graduate course on Intelligent Transportation Systems on April 6, 2017; and 3) a face-to-face discussion between Josh Cohen and Billy Williams and Shoaib Samandar of the STRIDE project team.

6.2 THE UBER INTEGRATION PILOT STUDY

In early 2016, TransLōc and the transportation network company (TNC) Uber announced a joint pilot of full integration in TransLōc's Rider trip planning app. The initial systems were the GoDurham system and the Memphis Area Transit Authority. The pilot study app provided a unique trip planning functionality in the service areas of these systems. Specifically, when the distance at either or both ends of a prospective transit trip was too long for comfortable walking (nominally considered to be longer than 1/4 mile), the app would propose an Uber trip to fill in this gap. Uber estimated time of arrival, estimated cost, and the ability to schedule Uber pickup and handle payment were integrated within the app. The experiences in Durham and Memphis provided the basis for app improvements, and the integrated service has been expanded to more than 10 total locations.

Although TransLōc considers the Uber integration a technical success, the pilot study and the subsequent expansion to other locations have revealed non-technical constraints and issues that severely limit the robustness of integrated transit-TNC ride planning as a primary solution to the first-mile/last-mile problem. Such constraints exist from the transit service provider, TNC, and traveler perspectives. Many transit service providers are not willing to allow or support TNC integration in transit trip planning tools. In some cases, this resistance arises from concerns that integration is as likely, if not more likely, to result in current transit trips migrating to TNC-only trips, as it is to result in new transit trips arising from the TNC solution to first-mile/last-mile gaps. A second sticking point for transit service providers is tied to the fact that to date, TNCs have demanded exclusivity as a condition for app integration. This puts a public sector transit agency in the position of tacitly favoring one TNC over all others who are or are considering offering service in the area. Another TNC constraint involves data sharing. In locations where integrated Transit-TNC trip planning applications are operational, the details regarding first-mile/last-mile TNC trips would be very valuable to the transit agency for ongoing system planning and improvement. However, as private business concerns, TNCs are generally not willing to provide data at a sufficient level of detail to support transit system planning.

In terms of the traveler perspective, the psychological inertia involved with travelers who have sworn off transit because of system gaps is significant. The education and marketing required to make headway in overcoming this inertia are therefore also significant. Given the TNC exclusivity demands mentioned above, it could be problematic for a public agency to expend sizeable resources on marketing that could be at least in part seen as working to increase business for a single service provider within what would ideally be a competitive service market. Finally, relying on TNCs to fill in system gaps in public transportation can lead to serious questions of fairness and equity. TNC service may be beyond the means of many citizens, and over time the service offered by for-profit TNCs will be disproportionately weighted toward wealthier, higher demand areas. These systematic and persistent issues that hamper the ability of TNCs to serve as a key player in the task of addressing the first-mile/last-mile problem have motivated TransLōc's decision to champion and provide tools for supporting agency-owned microtransit.

6.3   AGENCY-OWNED MICROTRANSIT

TransLōc's microtransit executive guide describes the following "practical examples" of microtransit –

- First-Mile/Last-Mile Service
- Off-Peak Flexible Service
- Underserved/Unserved On-Demand Services
- Building Demand for New Fixed Routes and Other Applications

The arguments for public ownership of microtransit services include the ability to solve the equity and data issues mentioned above. TransLōc also argues that public ownership facilitates the piloting and iterative improvement in new services and that with careful planning, agency-owned microtransit can remain vendor neutral and continue to partner with TNCs. For example, a transit agency may decide the TNCs are better suited to serve certain locations, such as adjoining rural areas.

TransLōc is now supporting microtransit efforts with several transit agencies. These services include planning support empowered by data-driven, predictive rider simulation models, and operational support through TransLōc Microtransit System, a "cloud-based, flexible-transit dispatching and monitoring system."

6.4 THE ROLE OF NON-MOTORIZED SHARED-MOBILITY SYSTEMS

In addition to agency-owned microtransit, TransLōc sees an important role for electric bicycle and electric scooter sharing in city centers and dense urban nodes. TransLōc leaders see both a significant and growing role for these systems for short intra-urban trips and as an efficient and effective first-mile/last-mile solution. Bikeshare and scooter-share systems are expanding rapidly, and in some locations, public agencies are struggling to decide how to deal with the sudden explosion privately-owned sharing systems. However, the rapid public acceptance and popularity of these systems underscore the potential of these systems to play a key role in urban mobility.

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8.0   APPENDIX A

COMPARING TRANSIT AGENCY PEER GROUPS USING CLUSTER ANALYSIS

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ABSTRACT

Transit ridership has decreased steadily each year from 2014 to 2017 despite increasing urban populations and transit investment. Several analyses have examined trends in national transit ridership levels or within specific agencies or regions. However, the causes of transit ridership changes, and the changes themselves are not likely to be the same everywhere. Thus, comparing the performance of transit agencies over time with their peers, which share similar characteristics, may yield more informative results than just examining national trends. This analysis groups metropolitan areas using relevant characteristics, which are correlated with transit ridership: total population, density, percent of zero vehicle households, and transit agency operating expenditures. Data from the National Transit Database and the United States Census Bureau were used. Trends in transit ridership are then analyzed in relation to population and service levels within each cluster and by family of modes. Results suggest that while the change in population and service levels can partly explain the change in ridership for transit modes in dedicated right-of-way, the same is not true for modes in mixed right-of-way. In particular, transit ridership for mixed right-of-way modes in large metropolitan areas is not significantly correlated with the change in population or service levels.

INTRODUCTION

Transit ridership in the United States has declined each year since 2014 despite increasing urban populations and new investments in transit service. Bus ridership, in particular, has dropped substantially with a 4.27% decrease in unlinked passenger trips in 2017 compared to 2016 [1]. There are likely many reasons for changing ridership. Automobile ownership, parking availability, cheap fuel, ride-hailing services, poor network coverage, and low-frequency service have been cited as causing decreased ridership [2-6]. However, the magnitude and causes of ridership changes are likely to vary from place to place [4]. There is a wide range of transit agencies that serve different populations, operate different services, and have drastically different budgets. These, and many other factors, are likely to substantially affect operations and ridership. It is unlikely that there is one sole cause of decreased ridership, and thus it is unlikely that there will be a single solution.

Ridership is influenced by factors that are both controlled by and external to an agency's actions. For example, agencies can control service frequency, but have little influence over population density in a service area. Factors outside of transit agencies control that are related to ridership include population size, density of persons or businesses, presence of high number of college students, and percentage of zero vehicle households [6]. Even operating expenses, which are typically considered as an internal factor, are by and large outside of agencies' control. These factors, which are structurally related to transit ridership but outside of agencies' control provide a framework to cluster metropolitan regions in groups of peers. This framework captures the main dynamics affecting regions that share common characteristics, and can allow us to better understand why specific regions stand out compared to their peers.

In this research, we will group metropolitan areas that operate transit service into groups on a set of variables that affect ridership but are outside of agencies' control. Using Ward's method, metropolitan regions will be clustered by mode family, separating mixed and dedicated right-of-way. Using this categorization, ridership trends between 2012 and 2016 will be analyzed based on changes in population and service-levels. The trends within each cluster, and the differences between clusters and mode-family will be shown in in the results section. Finally, the implications of the results will be discussed in the conclusions.

LITERATURE REVIEW

The factors that predict transit ridership have long been the subject of research. Many studies suggest that service levels are the most important variable related to transit ridership. Service levels are typically measured in vehicle revenue miles (VRM) or hours (VRH). In a simple one-variable regression of 265 urban areas, Taylor et al. (2009) found that VRH account for 95% of variation in ridership [6]. In a bus stop-level analysis of three cities in Oregon, Dill et al. (2013) found that characteristics in service, most notably headways, were the most important factors to determine ridership. Other factors accounting for ridership variation include population density, auto ownership, and fares [7]. In a panel regression of 25 North American regions, Boisjoly et al. (2018) found that auto ownership and vehicle revenue kilometers account for the most variation in transit ridership, and that fares were significantly correlated with ridership [3]. A panel study by B. Lee & Y. Lee (2014) found that gas prices had a larger effect on transit ridership in regions with higher density [8].

Much of the research cited in our review examines national trends, or trends within specific agencies. It is likely that the factors that influence ridership differ from city to city. To properly compare transit agencies, a more accurate approach may be to delineate different groups of transit agencies identified as similar using a parsimonious set of covariates. Many agencies "benchmark," their performance against agencies that they consider similar to their own. Benchmarking is typically performed using data reported to the Federal Transit Administration's National Transit Database (NTD). The NTD is updated annually and contains information about ridership, budgets, and operations. Many agencies use the NTD to compare themselves to other agencies, but NTD data is organized in a manner that makes it difficult to compare within agencies from year-to-year, let alone across agencies [9].

The Florida Department of Transportation created the Integrated National Transit Database Analysis System (INTDAS) to allow transit agencies to easily access and use NTD data available since 1984 [10]. This program has grown over time to include peer grouping functions for small and large transit agencies [11]. The system allows users to select 6-10 variables included in the final peer-grouping model, as well as 3 screening factors [11]. TCRP 141 and the Integrated National Transit Database that resulted from it are the first attempt to creating peer groups on a national scale [11]. However, this system is intended for specific benchmarking purposes rather than analysis. Many of the variables included to benchmark

are not necessarily relevant for research and analysis. In addition, the groupings vary depending on weights that are defined by the user. Therefore, no fixed set of peer agencies currently exists.

Other researchers have attempted to create peer groups for the purposes of comparing agency performance. The National Center for Transit Research developed a method to create peer groups based first on geographic region, then demographic and operational characteristics [12]. This effort was limited to bus service, however, and did not consider all agencies in the United States. An analysis by Brown and Neog splitting Metropolitan Statistical Areas (MSAs) into groups of smaller (500,000 to 1 million people) and larger MSAs (1-5 million people) found that changes in ridership were similar between the two groups [4]. In both groups, service frequency, service coverage, and percent of households not owning an automobile were significantly related to transit ridership. However, these effects were not observed when analyzing all MSAs together. Thus, comparing transit ridership amongst all agencies and MSAs can mask heterogeneous effects or suggest spurious correlations.

Although several methods have been developed to group peer agencies together for analysis of trends and benchmarking, a research gap still exists for analyzing transit services at the metropolitan level in order to analyze ridership trends. In this research, we will classify metropolitan areas according to metrics that are likely to influence transit ridership, and test the method to determine whether trends are different within the groups that are created.

METHODOLOGY

Analyzing transit ridership in metropolitan areas required manipulating census and NTD data to aggregate demographics and ridership at the metropolitan area level. This analysis thus required four major steps:

1. Preparation of census data
2. Preparation of NTD data
3. Clustering
4. Ridership trend analysis

Preparation of census data

Cartographic Boundary Shapefiles for Metropolitan and Micropolitan Statistical Areas and Related Statistical Areas were used as the base 2016 MSA/CBSA boundary shapefile, from which all census tracts with centroids inside MSA boundaries were extracted. Year 2016 Census tracts were derived from TIGER Line census tract shapefiles for all 50 US states and territories. Demographic and Housing estimates from the 5-year American Community Survey 2012-2016 were joined to the core census tracts based on a census tract ID common field using ArcMap. While population density is reported at the metropolitan

level, it is reported across an entire metropolitan area and may be influenced by depopulated areas that do not have any transit service. In other words, MSA level density may not reflect how many people actually live in dense areas that are amendable to transit. Thus, population density was defined using the Transit Capacity and Quality of Service Manual's definition of transit supportive density of 3 or more housing units in an acre [13]. We then defined density as the proportion of population that lives in an area with densities that support transit.

Preparation of National Transit Database data

The NTD organizes transit agencies into their corresponding Urbanized Area (UZA), a geographic area for which demographic data from the US Census is available every ten years. In many areas, several transit agencies serve the population, and data for each agency was aggregated up to the MSA level. In other words, all agencies reporting data that reside within a metropolitan area were included in a metropolitan area's transit ridership estimates.

Data from the 2016 American Community Survey was used in this analysis, but is only available for Core-Based Statistical Areas (CBSAs), a larger geographic unit than UZA's. Many CBSAs completely contain UZAs, but UZA and CBSA boundaries often conflict and overlap with one another. To reconcile these differences, geographic relationship files from the US Census were used to attribute transit statistics from the NTD into the appropriate CBSA by multiplying the values by the percentage of each UZA's population living within the appropriate CBSA. This process often resulted in small far-flung suburban or rural CBSAs being attributed a portion of their core UZA's transit statistics. To reconcile this, a UZA's statistics were thrown out for that CBSA if a CBSA contained less than 10% of the UZA's population. From here, ACS data was used to attribute demographic information to each CBSA, finalizing the CBSAs for the cluster analysis. There were 32 UZA's that were discarded using this rule. If there were inconsistencies in reporting (e.g. an agency stopped reporting halfway through a year, or did not report data on metrics included in the analysis), it was not included in the analysis.

Clustering

The clusters were created on the following metrics: metropolitan area population, percent of population living in a dense area, percent of zero vehicle households, and transit-agency operating expenses. To qualify as a variable to cluster on, data needed to be available for most transit agencies, and regularly reported. Next, variables needed to be related to transit ridership. Variables selected were correlated with transit ridership as discussed in the literature review above. However, the variables could not explain all variation in transit ridership. In other words, the variables should create groups which would be distinguishable from one another, but still contain within group variation in ridership. Several operational metrics were included and tested in the analysis, such as vehicle revenue miles, vehicle revenue hours, median number of vehicles operating at maximum service, and average cost per trip. However, operational metrics were highly correlated with one another. Thus, including several

operating metrics effectively overweights operations without explaining further variation between agencies. All agencies included in this analysis reported data on these metrics. Many non-operational metrics were also considered, including highway congestion, employment density, and parking pricing. While several of these variables are related to transit use, few are regularly reported in a standard format and available for all metropolitan regions. Thus, it was not possible to include these as criteria for clustering.

The four final variables selected have been shown to be related to transit ridership and are relatively stable over time [5, 6]. Population and percent of population living in dense areas accounted for most of the variation within and between clusters in the analysis. However, percentage of zero vehicle households and operating expenditures for different modes provided key distinctions in some cases.

After defining the metropolitan areas, and aggregating transit information in each area, cluster analyses were performed. Two cluster analyses were completed: one for transit services in dedicated right of way as defined in the NTD, and one for services not operating in a dedicated right of way. Metrics attributed to different modes were split according to mode for each clustering. For example, only those operating expenses for dedicated right of way services were included for the first cluster analysis. Agencies that operate mixed and dedicated right of way service were included in both clusters. This method captures the differences in operation and funding logistics that may be present for different modes within the same agency and region.

Dedicated right of way services included the following modes: heavy rail, light rail, monorail, commuter rail, and hybrid rail. Dedicated right of way services included only those systems which have 1 million or more unlinked passenger trips each year. The second group included all metro areas operating intra-city bus, commuter bus, bus rapid transit, and streetcar service. These services are not necessarily operating in a dedicated right of way according to the NTD. While some BRT and streetcar services do operate in their own right of way, it was not possible to distinguish which agencies did so. The NTD allows agencies to distinguish between light rail service and streetcar service with light rail noted as operating within dedicated right of way.

Ward's method of agglomerative hierarchical clustering was used to identify metropolitan areas with fixed characteristics that are similar in ways that are related to transit ridership. Ward's method was selected for this analysis because this method functions by minimizing the amount of intra-cluster variance and maximizing inter- cluster variance. Unlike k-means cluster analysis, in which the analyst must specify the number of clusters to create, Ward's method determines the optimal number of clusters by stopping when variance between clusters is maximized and variance within clusters is minimized. Ward's method is agglomerative in the sense that each case (metro area) begins as its own

cluster before sequentially combining with other cases. In addition, agglomerative clustering delineates the relative similarity between all metropolitan areas included in the analysis.

All values were scaled prior to running the cluster analyses in order to prevent metrics with large values from weighing more heavily on the cluster analysis. The magnitude of the differences between values within the same variable accounted for clustering rather than the magnitude of the values themselves. Other clustering methods were tested, including single and complete linkage clustering, and model-based clustering. The clusters were similar across the aforementioned methods. In all cluster solutions, the New York City metropolitan area was an outlier. It was not included in this analysis. The New York metro area accounted for nearly double the amount of all other dedicated right of way trips combined, and one-third of all mixed right of way passenger trips. The size of New York's transit network is orders of magnitude larger than other agencies in the United States. No other agencies would provide a meaningful comparison. New York's peer agencies are other large global agencies within the Community of Metros, or CoMET (https://cometandnova.org/). In terms of overall metropolitan size and density, Los Angeles was also an outlier. However, Los Angeles does not have an established peer group. It is included in this analysis to inform comparisons.

The ideal number of clusters is difficult to determine. There are numerous measures that compare methods' ability to create compact clusters that are also different from each other. In this analysis, scree plots, gap statistics, interpretability of the clusters were used to analyze different cluster solutions. There is not a perfect number of clusters, but only useful clusters that can assist analysts in gleaning more information from ridership trends. While several mechanical tests were conducted on the clusters, interpretability was ultimately the most important criteria for choosing the number of clusters.

Ridership trend analysis

For each dedicated and mixed right of way cluster, a trend analysis was conducted to examine relative changes in unlinked passenger trips between 2012 and 2016 compared to relative changes in population and service levels over the same period. These trends were plotted against one another to determine whether the trends were similar in magnitude and direction between each cluster. Chow tests were conducted on each relationship to determine whether the trend was the same amongst all clusters. Trends were also analyzed for zero vehicle households, but ultimately not included in the final analysis. Although zero vehicle household estimates are published annually, the estimates are relatively imprecise from year to year making trends difficult to detect. Data for the trend analysis were once again extracted from the American Community Survey, and NTD. One-year estimates from ACS were used for population figures. If transit data was not reported for the entirety of 2012 or 2016, the area was not included in the analysis.

RESULTS

In this analysis, we created clusters of metropolitan areas with similar characteristics related to transit ridership. Figure 1 below delineates the clusters for metropolitan areas operating dedicated right of way services with at least 1 million trips per year. Table 1 delineates the cluster analysis results for those metro areas that have dedicated right of way services. Based on the scree plots, gap statistics, and analyst interpretation, five clusters of metropolitan areas operating dedicated right of way services were selected.

Cluster one consisted of sprawling large metro areas with relatively few dense census tracts, many of which are located in the southern and western regions of the U.S. Most areas in this group had relatively similar levels of ridership between 15 and 32 million unlinked passenger trips, but Atlanta and Virginia Beach stood out. Atlanta has much higher ridership (71.6 million unlinked passenger trips) than other areas in cluster 1, but also operates heavy rail services and spends at a level appropriate for heavy rail operations. Virginia Beach, on the other hand, had only 1.3 million unlinked passenger trips, but was similar on other metrics. The metropolitan areas in Cluster 1 tended to have the least number of people living in densely populated areas with 7-35% of persons in these metros living in dense areas.

The second cluster consists of cities that are relatively small, compact, and with a high percentage of zero vehicle households. This includes former industrial hubs in Baltimore, Buffalo, Cleveland, and Pittsburgh. These cities have 1.1 to 2.3 million people, and at least 27% of their populations live in dense census tracts. All four of these areas experienced their highest growth rates before the 1950s when compact urban development was the norm and have rapidly declined in population, industry, and economic activity since then. San Juan is the largest city in Puerto Rico, is a former industrial hub, and is one of the oldest cities in the Americas. Similar to the aforementioned cities, it has a relatively compact urban form with 43% of persons living in dense areas, and disproportionately high percentage of zero vehicle households. Baltimore has a disproportionally high amount of ridership in this cluster.

The third cluster includes Chicago, Boston, Philadelphia, San Francisco, and Washington D.C. These are large metro areas with extensive transit systems and large commuter rail networks. Like the cities in cluster 2, the cluster 3 cities developed before the relatively newer cities in the South, and Mountain West. All three cities spend at least $250 million per year on rail operations, and have ridership in excess of 149 million unlinked passenger trips. Of all the clusters, these cities have the highest percentage of zero vehicle households with 12-13%. These cities are large and dense with 4.5-6 million people and close to half the population living in dense areas. Regions in this cluster invest heavily in transit operations, with 4 out of 5 spending in excess of $900 million in operating expenses each year.

Cluster four consists of medium sized metro areas that are mainly in the western areas of the country. These cities have low percentages of zero vehicle households (6-9%), but a high proportion of

population living in dense census tracts (43-74%). The transit systems in these areas tend to be relatively new, and are growing quickly. Most of the systems contained in this cluster are light rail systems rather than the legacy heavy rail systems in Cluster 3.

The Los Angeles metropolitan area was an outlier in this grouping. It is unusually large with a higher percentage of people in dense areas, but with very low investment in dedicated right of way service. It was thus included in Cluster #5 by itself. For the size of the population and amount of people in dense areas, Los Angeles has 115 million unlinked passenger trips, relatively low for such a large, dense area with dedicated right of way services.
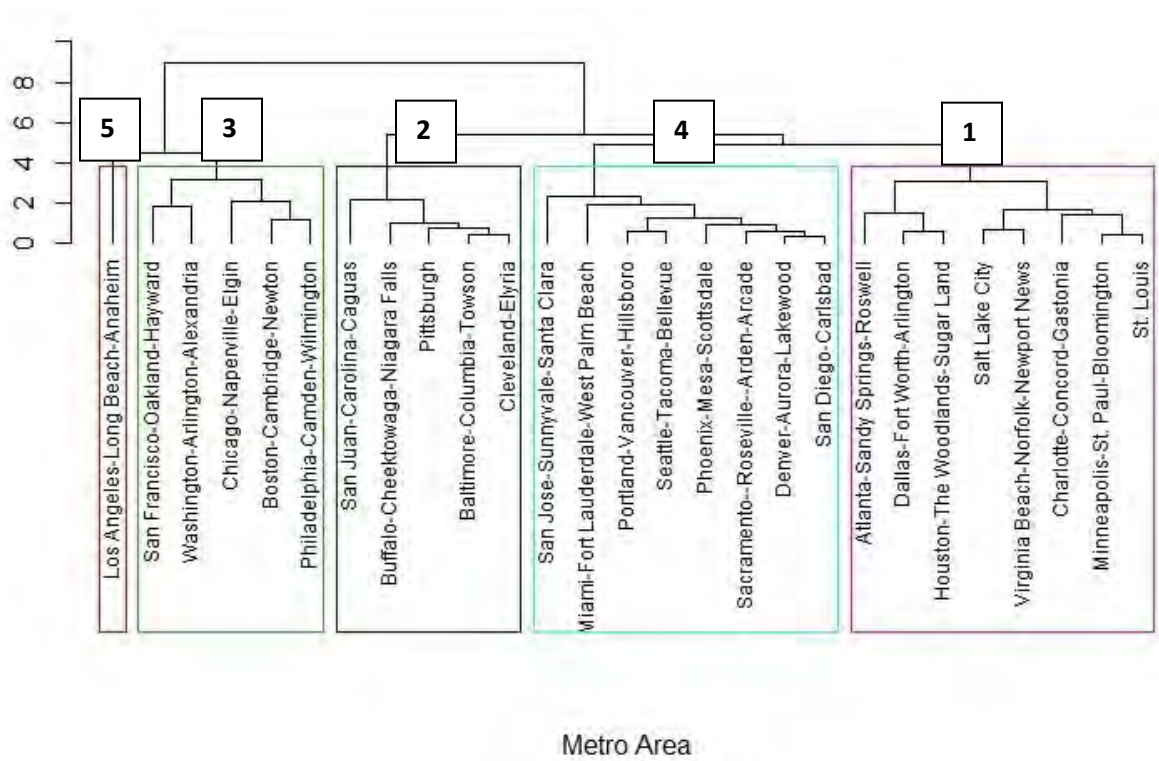
Figure 1. Dedicated Right of Way Cluster Dendrogram

Table 1. Clusters of metropolitan areas operating dedicated right of way services

Cluster	Metro	Population	% Zero Vehicle Households	% living in dense tracts	Rail OpEx	UPT
1	Atlanta-Sandy Springs-Roswell	5,612,777	6%	11%	225,442,322	71,628,767
	Charlotte-Concord-Gastonia	2,381,152	6%	7%	14,344,018	4,898,810
	Dallas-Fort Worth-Arlington	6,957,123	5%	28%	221,001,338	32,361,412
	Houston-The Woodlands-Sugar Land	6,482,592	6%	31%	61,232,514	18,532,122
	Minneapolis-St. Paul-Bloomington	3,488,436	7%	23%	83,213,303	23,674,796
	St. Louis	2,803,449	8%	21%	79,589,101	15,777,584
	Salt Lake City	1,154,504	5%	35%	112,333,930	23,744,484
	Virginia Beach-Norfolk-Newport News	1,714,428	7%	28%	12,095,865	1,369,483
2	Baltimore-Columbia-Towson	2,780,873	11%	39%	229,704,362	27,859,468
	Buffalo-Cheektowaga-Niagara Falls	1,135,503	13%	38%	23,583,586	5,212,083
	Cleveland-Elyria	2,061,630	11%	36%	46,918,226	8,345,656
	Pittsburgh	2,354,926	11%	27%	60,301,731	8,132,130
	San Juan-Carolina-Caguas	2,230,563	17%	43%	67,442,732	8,203,745
3	Boston-Cambridge-Newton	4,728,844	13%	39%	901,461,300	260,852,360
	Chicago-Naperville-Elgin	9,528,396	12%	47%	1,363,777,343	314,439,498
	Philadelphia-Camden-Wilmington	6,047,721	13%	42%	572,352,684	149,765,472
	San Francisco-Oakland-Hayward	4,577,530	12%	66%	952,050,745	208,138,425
	Washington-Arlington-Alexandria	6,011,752	10%	41%	1,070,038,562	253,044,328
4	Denver-Aurora-Lakewood	2,752,056	6%	49%	151,248,917	28,885,146
	Miami-Fort Lauderdale-West Palm Beach	5,926,955	9%	61%	213,934,864	35,988,255
	Phoenix-Mesa-Scottsdale	4,486,153	6%	45%	41,487,087	16,511,814
	Portland-Vancouver-Hillsboro	2,351,319	8%	43%	136,527,502	40,651,493
	Sacramento--Roseville--Arden-Arcade	2,242,542	7%	47%	58,932,333	12,216,162
	San Diego-Carlsbad	3,253,356	6%	54%	108,556,541	43,848,882
	San Jose-Sunnyvale-Santa Clara	1,943,107	5%	74%	92,391,496	10,716,759
	Seattle-Tacoma-Bellevue	3,671,095	8%	38%	133,773,904	25,548,913
5	Los Angeles-Long Beach-Anaheim	13,189,366	8%	77%	642,977,890	115,780,149

In Table 2 below, the clusters for mixed right of way are listed. In addition, Figure 2 visually displays the distribution of agencies by cluster across the country. Table 3 displays the summary statistics for each cluster. As with the dedicated right of way clusters, there are similarities within clusters that are related to geography and development patterns. Cluster one in this analysis is qualitatively similar to cluster 2 in the dedicated right of way analysis, and includes many of the same areas. It features older industrial cities that are typically in Northeast and Midwest that have declined in population in the past several decades. These areas have a relatively high percentage of zero vehicle households (6.4%-16.7%), and are typically small to midsize metro areas with the median metro in this group at 633,668 people.

Cluster two primarily features small to mid-size, recently developed cities in the Midwest and South with low percentages of people living in zero vehicle households (3.7-8.3%). However, these areas are similar to those in cluster one in terms of percentage of dense population with the median area at 22.3% living in a dense tract.

Cluster 3 consists of the smallest cities operating fixed route transit service in this analysis, and includes a disproportionate number of "college towns." The metro areas in this cluster are the least dense, least populated, and spend the least on transit of the agencies included in this analysis. Ridership in this group reflects these numbers as this group has the lowest number of unlinked passenger trips with the median area having 1.5 million unlinked passenger trips.

Cluster four is similar to cluster one in the dedicated right of way analysis. The cities in cluster four are sprawling, large cities that have a low percentage of zero vehicle households (5-8.5%). No city in this cluster has fewer than 1.9 million people. Operating expenditures in this cluster reflect the large population of these areas, with the median area spending $268 million in operating expenditures.

Last, cluster five consists of the largest metro areas in the country with populations between 3.6 and 13.2 million. These areas invest heavily in transit with median operating expenditures at $836 million. Metro areas in this cluster are very dense compared to those areas in clusters one to three, but comparable to metros in cluster four. Unlike the dedicated right of way analysis, Los Angeles is included in cluster five in this iteration. This is because Los Angeles area transit agencies invest in bus operations at a level more in line with the size and density of the metropolitan area. The regions in cluster five spend substantially more on bus operations than regions in other clusters and subsequently have substantially higher ridership. The range in ridership for cluster five is 111-480 million unlinked passenger trips. The highest ridership outside this cluster is 81 million unlinked passenger trips.

Table 2. Non-Dedicated Right of Way Clusters

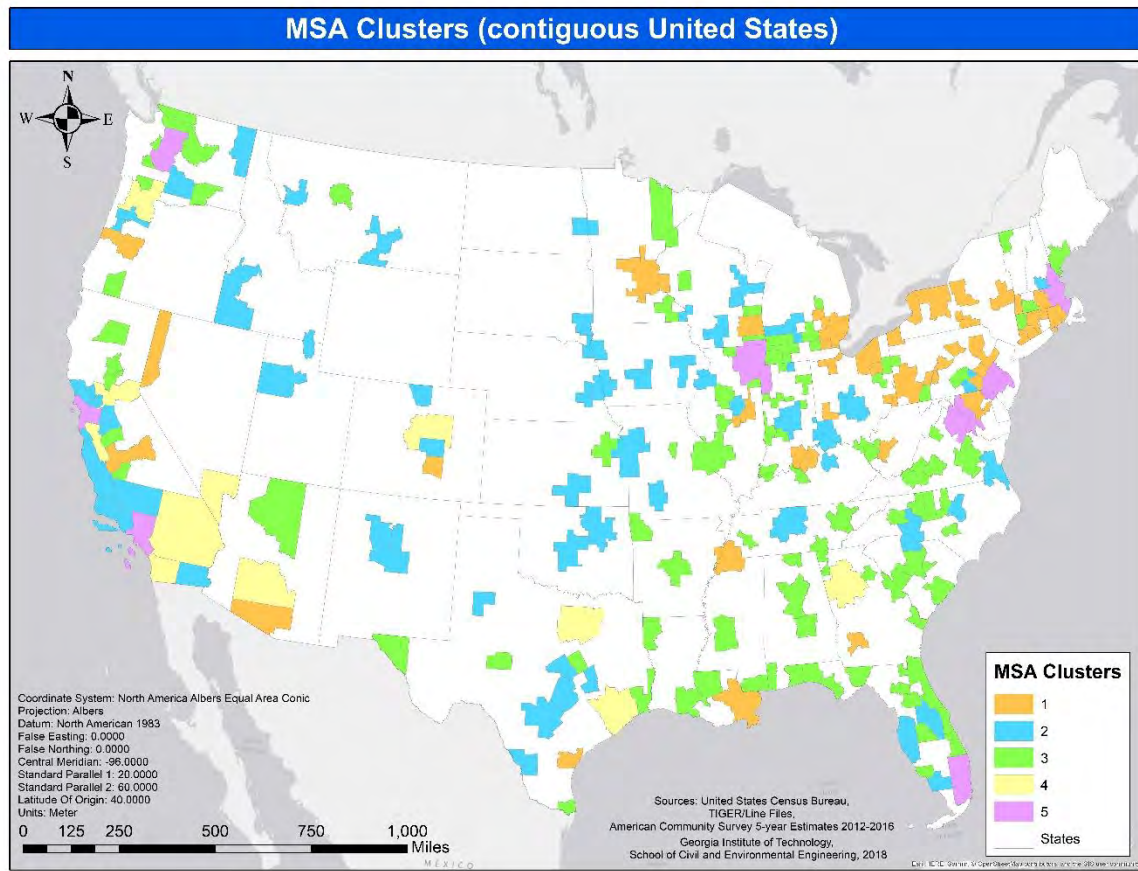|	Metro Area
1	**Midwest:** Akron, Ann Arbor, Champaign-Urbana, Cleveland-Elyria, Dayton, Decatur, Detroit-Warren-Dearborn, Flint, Memphis, Milwaukee-Waukesha-West Allis, Minneapolis-St. Paul-Bloomington, Saginaw, St. Cloud, Toledo, Wheeling OH-WV **North:** Albany-Schenectady-Troy, Allentown-Bethlehem-Easton, Altoona, Baltimore-Columbia-Towson, Binghamton, Bridgeport-Stamford-Norwalk, Buffalo-Cheektowaga-Niagara Falls, Erie, Hartford-West Hartford-East Hartford, Ithaca, Johnstown, Lancaster, New Haven-Milford, Pittsburgh, Pittsfield, Providence-Warwick, Reading, Rochester NY, Scranton--Wilkes-Barre—Hazleton, State College, Syracuse, Williamsport, Worcester **South:** Albany GA, Charleston WV, Corpus Christi, Louisville/Jefferson County, New Orleans-Metairie **West:** Eugene, Fresno, Pueblo, Reno, Tucson, Urban Honolulu **Puerto Rico**: San Juan-Carolina-Caguas,
2	**Midwest:** Ames, Appleton, Bloomington, Cedar Rapids, Cincinnati, Columbus, Davenport-Moline-Rock Island, Des Moines-West Des Moines, Fargo, Grand Rapids-Wyoming, Green Bay, Indianapolis-Carmel-Anderson, Iowa City, Kansas City, La Crosse-Onalaska, Lawrence, Lincoln, Madison, Omaha-Council Bluffs, Oshkosh-Neenah **North:** Lebanon, Manchester-Nashua, York-Hanover **South:** Austin-Round Rock, Charlotte-Concord-Gastonia, College Station-Bryan, El Centro, Killeen-Temple, Laredo, Lexington-Fayette, Logan, Lubbock, Naples-Immokalee-Marco Island, Nashville-Davidson--Murfreesboro—Franklin, North Port-Sarasota-Bradenton, Oklahoma City, Orlando-Kissimmee-Sanford, Raleigh, San Antonio-New Braunfels, Tampa-St. Petersburg-Clearwater, Tulsa, Virginia Beach-Norfolk-Newport News **West:** Albuquerque, Anchorage, Bakersfield, Billings, Boise City, Colorado Springs, Corvallis, Fort Collins, Kahului-Wailuku-Lahaina, Missoula, Modesto, Napa, Oxnard-Thousand Oaks-Ventura, Salem, Salinas, Salt Lake City, San Luis Obispo-Paso Robles-Arroyo Grande, Santa Cruz-Watsonville, Santa Fe, Santa Maria-Santa Barbara, Santa Rosa, Sioux City, Sioux Falls, Spokane-Spokane Valley, Springfield MO, Stockton-Lodi, Vallejo-Fairfield, Wichita, Yakima
3	**Midwest:** Bay City, Bloomington, Canton-Massillon, Columbia MO, Duluth, Eau Claire, Elkhart-Goshen, Evansville, Fayetteville-Springdale-Rogers MO, Fort Wayne, Great Falls, Holland, Huntington-Ashland, Jackson MI, Kalamazoo-Portage, Kankakee, Kennewick-Richland, Kokomo, Lafayette-West Lafayette, Lansing-East Lansing, Muncie, Niles-Benton Harbor, Peoria, Racine, Redding, Rochester MN, Rockford, Sheboygan, South Bend-Mishawaka, Springfield IL, St. Louis, Terre Haute, Topeka **North:** Burlington-South Burlington, , Harrisburg-Carlisle, Medford, Portland-South Portland ME, Somerset, Springfield MA, Torrington, Youngstown-Warren-Boardman **South:** Athens-Clarke County, Augusta-Richmond County, Baton Rouge, Beaumont-Port Arthur, Birmingham-Hoover, Blacksburg-Christiansburg-Radford, Brownsville-Harlingen, Cape Coral-Fort Myers, Columbia SC, Charleston-North Charleston, Chattanooga, Crestview-Fort Walton Beach-Destin, Deltona-Daytona Beach-Ormond Beach, Durham-Chapel Hill, Elizabethtown-Fort Knox, El Paso, Fayetteville NC, Gainesville, Greensboro-High Point, Gulfport-Biloxi-Pascagoula, Harrisonburg, Hickory-Lenoir-Morganton, Huntsville, Jackson MS, Jackson TN, Jacksonville, Knoxville, Lafayette LA, Lakeland-Winter Haven , Little Rock-North Little Rock-Conway, Lynchburg, Mobile, Montgomery, Ocala, Palm Bay-Melbourne-Titusville, Panama City, Pensacola-Ferry Pass-Brent, Port St. Lucie , Richmond, Roanoke, Rome, San Angelo, Savannah, Sebastian-Vero Beach, Shreveport-Bossier City, Sumter, Tallahassee, Waco, Winston-Salem **West:** Bellingham, Bremerton-Silverdale, Chico, Flagstaff, Hanford-Corcoran, Longview, Merced, Mount Vernon-Anacortes, Olympia-Tumwater, Wenatchee
4	**South:** Atlanta-Sandy Springs-Roswell, Dallas-Fort Worth-Arlington, Houston-The Woodlands-Sugar Land **West:** Denver-Aurora-Lakewood, Las Vegas-Henderson-Paradise, Phoenix-Mesa-Scottsdale, Portland-Vancouver-Hillsboro Riverside-San Bernardino-Ontario, Sacramento--Roseville--Arden-Arcade, San Diego-Carlsbad, San Jose-Sunnyvale-Santa Clara
5	**North:** Boston-Cambridge-Newton, Philadelphia-Camden-Wilmington, Washington-Arlington-Alexandria **Midwest:** Chicago-Naperville-Elgin **West:** Los Angeles-Long Beach-Anaheim, San Francisco-Oakland-Hayward, Seattle-Tacoma-Bellevue, **South:** Miami-Fort Lauderdale-West Palm Beach

Figure 2. Metropolitan areas by mixed right of way cluster.

Table 3. Summary Statistics for mixed right of way services by metropolitan area cluster

Cluster		Population	% Zero Vehicle Households	% living in dense tracts	Bus OpEx	UPT
1	Range	104,200-4,296,700	6.4%-16.7%	0-49.3%	$2,506,844-$357,454,900	385,867-81,710,000
	Standard deviation	884,432	1.72%	11.3%	83,427,600	18,902,560
	Median	633,668	9.56%	23.5%	$32,381,400	7,276,300
	Mean	881,964	9.74%	23.7%	$63,092,700	14,125,000
2	Range	87,455-2,927,700	3.7%-9.0%	3.3%-46.2%	$1,286,600-$168,001,726	330,800-37,773,800
	Standard deviation	725,155	1.1%	10.0%	36,779,327	7,705,000
	Median	429,596	5.8%	22.4%	$14,322,500	3,193,700
	Mean	726,608	5.9%	23.6%	$ 29,263,570	6,064,800
3	Range	76,200-2,803,449	4.0%-12.2%	0-38.0%	$283,300-$176,173,118	32,200-30,193,100
	Standard deviation	354,029	1.2%	6.3%	20,082,061	3,948,000
	Median	312,891	6.8%	5.6%	$6,656,044	1,526,000
	Mean	390,472	6.8%	7.2%	$12,104,306	2,656,800
4	Range	1,943,100-6,957,100	5.0%-8.5%	10.7%-73.8%	$120,238,100-$393,664,400	20,422,200-73,208,400
	Standard deviation	1,748,366	1.14%	17.7%	80,409,100	18,463,500
	Median	3,253,356	6.0%	45.0%	$268,816,200	66,073,400
	Mean	3,871,075	6.2%	43.4%	$250,269,900	54,173,000
5	Range	3,671,000-13,189,300	8.0%-13.2%	38.5%-77.4%	$474,128,600-$1,750,256,700	111,341,80-480,925,400
	Standard deviation	2,940,498	2.8%	13.71%	376,773,400	110,936,000
	Median	5,926,955	11.0%	44.5%	$881,421,200	203,293,200
	Mean	6,710,207	10.8%	51.3%	$931,496,905	230,068,870

Trend Analyses

Trend analyses were conducted on both the mixed right of way and dedicated right-of-way clusters. These analyses show how the change in ridership relates to changes in factors that have been shown to be highly correlated with transit ridership in past studies [3,6]. Although multiple trends were examined, the changes in population and vehicle revenue miles were the most relevant, as both have been cited as related to recent ridership trends. The results are presented below. If the coefficient on the variable in a univariate regression was significant, the trend line and R^2 were included.

Dedicated Right-of-Way

The percentage change in population, and vehicle revenue miles were significantly correlated with transit ridership for dedicated right of way services. Figure 3 shows the percent change in unlinked passenger trips (UPT) against the percentage change in population (top) and vehicle revenue miles (bottom). In both the top and bottom figures, the relationships are strong. A Chow test was performed on the trends to determine if the trend lines were different for each cluster. For the population changes, the test suggested that the trends were similar across all clusters (p = .099). For the VRM trend lines, the test was significant at the 95% level (p = .0126). In both figures, however, three outliers, Houston, Minneapolis, and Seattle, disproportionately increased ridership. All three areas introduced new dedicated right of way services during the analysis period. Therefore, the relationship between ridership change and population change and service level change would be even greater if not for these three. The difference in trend lines is likely related to these outliers.
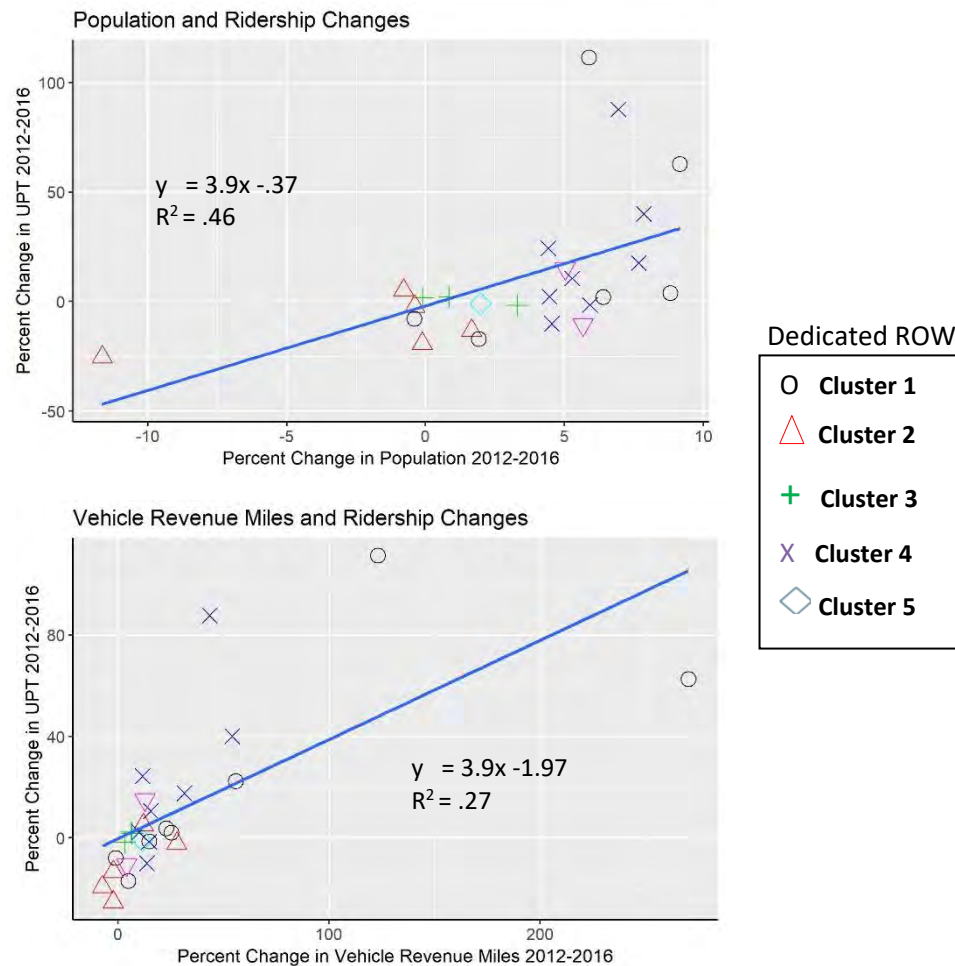
Figure 3. Percentage change in ridership relative to percentage changes in population, and vehicle revenue miles for dedicated right of way transit services, 2012-2016

Mixed Right-of-Way

Figures 4 and 5 below display the percentage changes in unlinked passenger trips against percentage changes in population and vehicle revenue miles, respectively. These analyses suggest that population and ridership changes were not uniform across each cluster and that the relationships between ridership and the selected variables differ. Chow tests were also conducted on the population and VRM regression lines. Once again, the test suggests that the coefficients were not statistically different for the population comparisons (p = .146), but were significant for the vehicle revenue mile comparisons (p = .00). This result suggests that the relationship between population and ridership is relatively similar across metropolitan areas, but changes in vehicle revenue miles are different.

Population

Figure 4 below displays the change in population relative to changes in ridership from 2012 to 2016 in each cluster. Cluster 1 consists of smaller cities that either decreased in population or increased by less than 10% between 2012 and 2016. Ridership had a small, but positive relationship with changes in population in these metro areas (R^2 in the univariate regression was .15). However, this relationship is heavily influenced by a single outlier, San Juan, Puerto Rico. This cluster stands in contrast to the metros in cluster 2, where there were no cities that lost population, and several grew by more than 10%. However, the relationship between population growth and ridership in this cluster was not clear and the trend was flat (Figure 4, $R^2=0.00$). Cluster 3 featured cities with relatively stable populations. Transit ridership was positively correlated with population increases in these areas, but only slightly and explained almost no variation ($R^2=0.01$). Cluster 4 features large metro areas that are sprawled and auto-oriented, while Cluster 5 features large metro areas that are dense and relatively transit-oriented. Although every metro region in Cluster 4 grew by more than 4% between 2012 and 2016, there is no clear relationship with the change in transit ridership ($R^2=0.00$). In Cluster 5, where population growth was more moderate, there is a slight trend, but it does not explain much of the variation in ridership ($R^2=.14$).

Vehicle revenue miles

As shown in Figure 5, Clusters 1-3 demonstrated a similar relationship between vehicle revenue miles and ridership. In these medium (Clusters 1 and 2) and small (Cluster 3) metropolitan regions, the change in service levels was positively and significantly correlated with the change in transit ridership (R^2 values ranged from .18 to .38 in each). Note, however, that for all three clusters, the y-intercept is negative (-11.9, -7.9, -8.0 respectively). Transit agencies in small and medium metro areas that did not change the amount of service provided thus experienced ridership of 8-12% between 2012 and 2016, on average. In Cluster 4 and 5, however, the relationship between the change in ridership and service levels is negative or null ($R^2=0.09$ for Cluster 4; $R^2=0.00$ for Cluster 5). These results indicate that the recent decline in ridership in large metro areas is not correlated with a decline in service levels. To the contrary, most metro areas in both clusters both increased service and lost ridership in mixed right of way services.
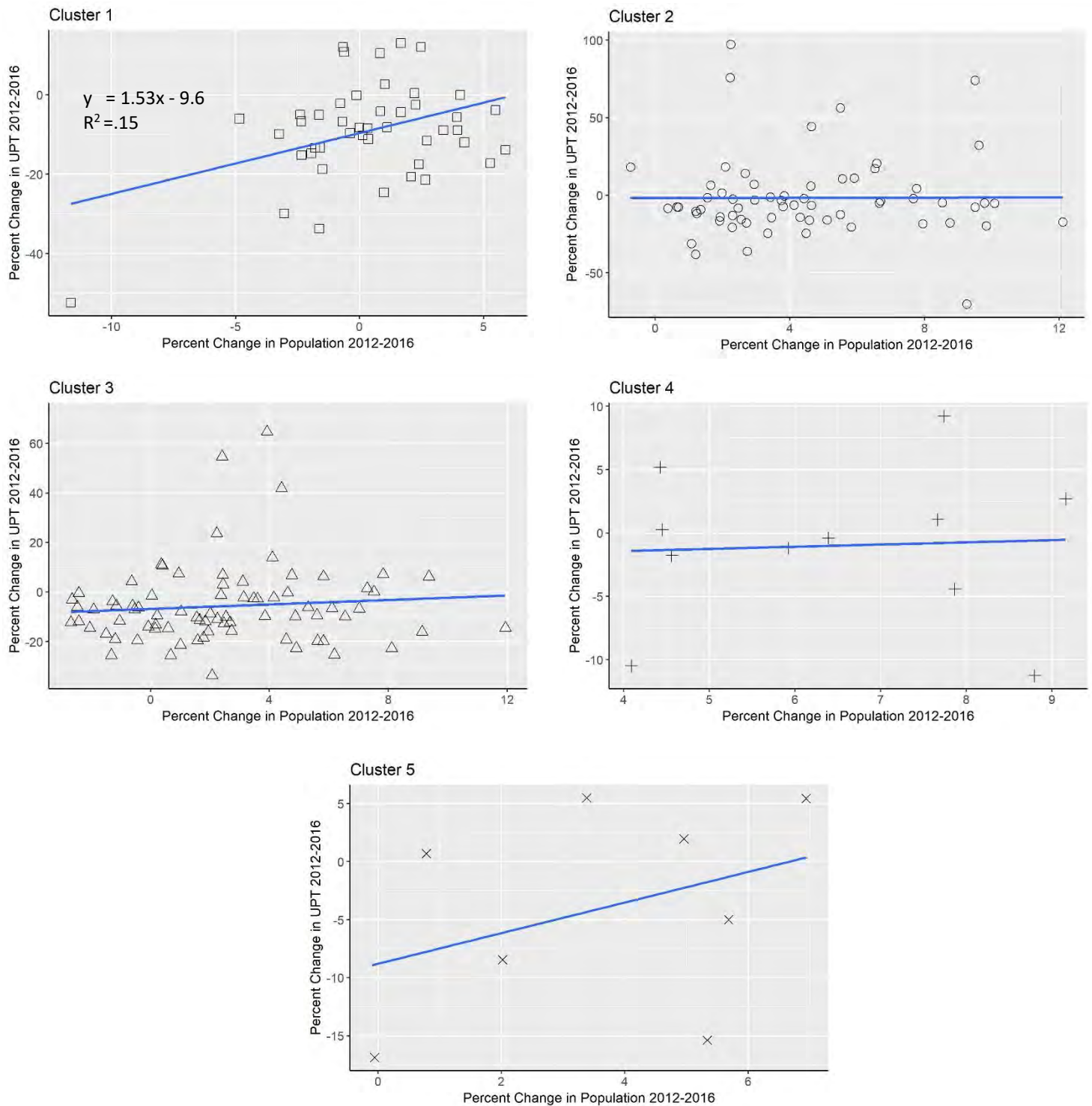
Figure 4. Percentage change in ridership and percentage change in population by cluster, 2012-2016
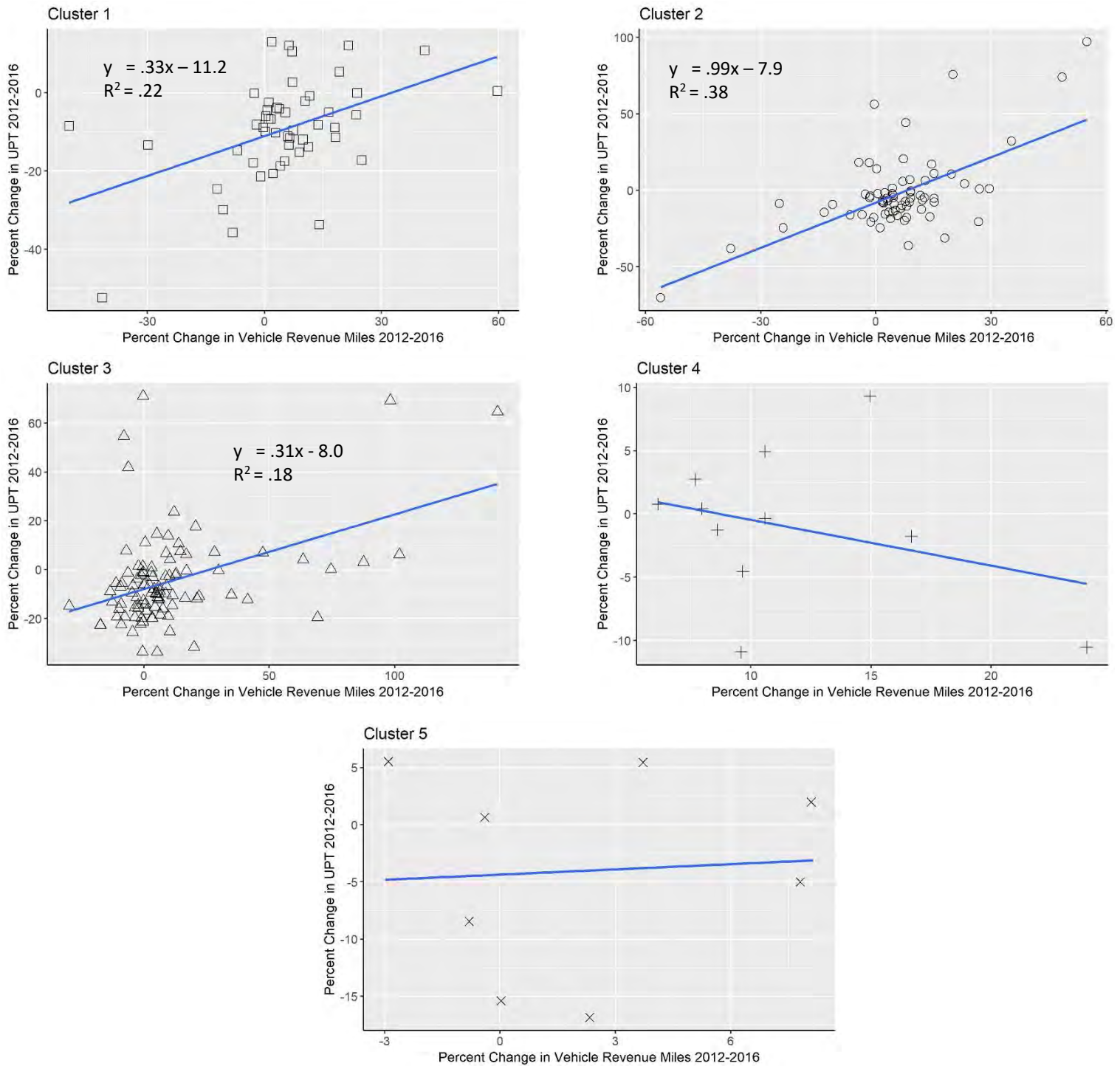
Figure 5. Percentage change in ridership and percentage change in vehicle revenue miles by cluster, 2012-2016

CONCLUSIONS

Transportation is changing dramatically. Determining the causes of changes in transit ridership is critically important for operations and funding decisions for transit and transportation. Understanding trends will help agencies deliver better service, and governments invest limited funding more effectively. While it is useful to track ridership trends at the national level or for a few of the largest agencies, such analysis only yields limited insight. Transit ridership is directly influenced by demographic and land use characteristics that can measured relatively easily. With a parsimonious set of variables shown to influence transit ridership, it is possible to classify transit agencies into groups to analyze ridership trends. Rather than comparing a single transit agency against average performance metrics in the United States, it is more informative to compare trends within groups of similar agencies and metropolitan areas. Analyzing ridership trends within said groups can yield results that are informative, specific, and actionable. Researchers and practitioners alike can benefit from understanding how the relationships between key metrics vary depending on the context in which services operate.

To date, research has not extensively analyzed ridership in groups classified on demographic and land use characteristics, but has been limited to examining trends at national and agency levels. This analysis applies to transit ridership at metropolitan rather than agency levels alone. While transportation agencies and funding typically follow jurisdictional lines, the land use demographics of metropolitan areas heavily influence transit ridership. Further, "service areas" are defined differently by every agency and may not reflect where riders are from. Examining the performance of transit ridership at the metropolitan level examines whether the needs of the population living in those areas are met.

Notably, this analysis suggests that changes in ridership and their causes are not uniform across modes and clusters. While the change in both population and service levels was closely associated with the change in transit ridership for dedicated right-of-way modes, the same was not true for mixed right-of-way modes. The change in population had little correlation with the change in ridership across mixed right-of-way modes. The change in service levels was correlated with ridership change for Clusters 1, 2, and 3 (small and medium metro areas) but with strongly negative intercepts, and not significantly correlated for Clusters 4 and 5 (large metro areas). These results indicate that even within clusters of peers, when analyzed at the regional level, population and service levels, which have been identified in the past as major determinants of ridership, do not explain the recent decline in transit ridership. Therefore, some other factors are causing the decline in ridership. Future research should investigate the causes of transit ridership on a more disaggregated level to identify the underlying dynamics at play.

Finally, an indirect benefit to creating these clusters is that they can be used as peer-groups for transit agencies to benchmark against one another. Benchmarking is a key component of strategic planning and process improvement. An analysis of small to mid-size U.S. transit agencies suggests that strategic planning and performance measurement contribute to improved performance metrics listed in the National Transit Database [14]. This is especially difficult for smaller areas that may have limited staff capacity and resources to determine whom their peers may be. Creating peer-groups by clustering on relatively few variables assists in making the peer-groups more intuitive and easy to understand for transit agencies.

ACKNOWLEDGEMENTS

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