U.S. Department of Transportation
Federal Highway Administration

Tier 1 University Transportation Center (UTC) Match Funds for the Strategic Implications of Changing Public Transportation Travel Trends

Transit – Serving Communities Optimally, Responsively, and Efficiently (T-SCORE) Center

Research Final Report from University of Tennessee, Knoxville | Candace Brakewood, Christopher Cherry, Abubakr Ziedan, Nitesh Shah, Sameer Aryal, Ashley Hightower, Grace Whitehouse March 31, 2023

THE UNIVERSITY OF TENNESSEE KNOXVILLE

Sponsored by Tennessee Department of Transportation Long Range Planning Research Office & Federal Highways Administration

DISCLAIMER

This research was funded through the State Planning and Research (SPR) Program by the Tennessee Department of Transportation and the Federal Highway Administration under ***RES 2021-15: Transit – Serving Communities Optimally, Responsively, and Efficiently (T-SCORE) Center***.

This document is disseminated under the sponsorship of the Tennessee Department of Transportation and the United States Department of Transportation in the interest of information exchange. The State of Tennessee and the United States Government assume no liability of its contents or use thereof.

The contents of this report reflect the views of the author(s) who are solely responsible for the facts and accuracy of the material presented. The contents do not necessarily reflect the official views of the Tennessee Department of Transportation or the United States Department of Transportation.

Technical Report Documentation Page

1. Report No. RES2021-15	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle *Tier 1 University Transportation Center Match Funds for the Strategic Implications of Changing Public Transportation Travel Trends: Transit – Serving Communities Optimally, Responsively, and Efficiently (T-SCORE)*		5. Report Date March 31, 2023 6. Performing Organization Code University of Tennessee, Knoxville
7. Author(s) Candace Brakewood, PhD, Principal Investigator Christopher Cherry, PhD, Co-Principal Investigator Abubakr Ziedan, Graduate Research Assistant Nitesh Shah, Graduate Research Assistant Sameer Aryal, Graduate Research Assistant Ashley Hightower, Undergraduate Research Assistant Grace Whitehouse, Undergraduate Research Assistant		8. Performing Organization Report No.
9. Performing Organization Name and Address University of Tennessee, Knoxville 851 Neyland Drive Knoxville, TN 37996		10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address Tennessee Department of Transportation 505 Deaderick Street, Suite 900 Nashville, TN 37243		13. Type of Report and Period Covered 14. Sponsoring Agency Code

15. Supplementary Notes
Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. Abstract
Even before the onset of the COVID-19 pandemic, public transit ridership was declining in many metropolitan areas in the United States. To regain riders, transit agencies and their partners must make decisions about which strategies and policies to pursue within the constraints of their operating environments. To help address this, the Transit-Serving Communities Optimally, Responsively, and Efficiently (T-SCORE) Tier 1 University Transportation Center was set up as a research consortium from 2020 to 2023 led by Georgia Tech with research partners at the University of Kentucky, Brigham Young University and University of Tennessee, Knoxville (UTK). The T-SCORE Center had two primary research tracks: (1) Community Analysis (led by the University of Tennessee; included in this report) and (2) Multi-Modal Optimization and Simulation (led by the University of Kentucky; not included). The Community Analysis research track employed a combination of quantitative and qualitative research methods to assess three main drivers of change that have affected transit ridership: price and socioeconomic factors, the competitive landscape, and system disruptions, including COVID-19. The research approach for the Community Analysis track was divided into separate projects, and the UTK team led three projects that aimed to: (1) quantify the impact of different factors affecting transit ridership - including the COVID-19 pandemic - at a nationwide scale; (2) assess the impacts of shared micromobility, particularly electric scooters, on transit ridership; and (3) evaluate new fare payment technologies and emerging pricing strategies, with the vision of taking a step toward Mobility-as-a-Service (MaaS). The findings of these three Community Analysis projects can help inform transit agencies and city officials making decisions about how to increase transit ridership and plan for a sustainable future.

17. Key Words	18. Distribution Statement
PUBLIC TRANSIT, RIDERSHIP, MICROMOBILITY, FARES AND PRICING, MOBILITY AS A SERVICE	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	27	

Acknowledgements

This research was supported by a grant from the U.S. Department of Transportation (USDOT) through the University Transportation Center (UTC) program (USDOT Grant 69A3552047141) with matching funds from Tennessee Department of Transportation (TDOT). The authors would like to thank the USDOT and TDOT for their support of university-based research in transportation, and especially for the funding provided in support of this project.

We would also like to recognize all of the members of the T-SCORE Tier 1 University Transportation Center consortium. The other collaborators include lead institution Georgia Tech in addition to the University of Kentucky and Brigham Young University. We would like to acknowledge the investigators (listed below) and their students (not listed) from each of the partner universities:

1. **Georgia Tech:** Dr. Kari Watkins (Center Director, now at University of California, Davis), Dr. Michael Hunter, Dr. Pascal Van Hentenryck, and Dr. Srinivas Peeta
2. **University of Kentucky:** Dr. Gregory Erhardt
3. **Brigham Young University:** Dr. Gregory Macfarlane

We are very grateful to the Tennessee Department of Transportation staff who provided input on this research project, particularly Melanie Murphy and Jonathon Haynes from the Research Office.

We would also like to acknowledge our local partners, particularly WeGo Transit in Nashville, Tennessee for their support of the micromobility and mobility-as-a-service (Maas) research. We are particularly grateful to Justin Cole.

An important part of research is the dissemination of the methods and results to other researchers and practitioners. The following is a list of primary research products that are associated with this project and were supported in part by the TDOT matching funds. Additional research projects from the T-SCORE Center supported primarily by USDOT funds, or other university partner matching funds can be found on the T-SCORE website here: https://tscore.gatech.edu/

Presentations:

1. Ziedan, Hightower, Brakewood, and Lima. The Impacts of Fare Capping on Bus Ridership. Poster presentation at the 102nd Annual Meeting of the Transportation Research Board (TRB) in Washington, DC, January 2023.
2. Ziedan, Brakewood, Watkins. Transit Ridership during COVID-19: An Exploratory Analysis of Nationwide Trends. Poster Session. Poster presentation at the 102nd Annual Meeting of the Transportation Research Board (TRB) in Washington, DC, January 2023.
3. Ziedan, Shah, Brakewood, and Cherry. A Method for Placing Shared E-Scooters Corrals Near Transit Stops. Presentation at the 2022 Tennessee American Planning Association and Tennessee Section of the Institute of Transportation Engineers (TAPA/TSITE), Fall 2022.
4. Ziedan, Shah, Brakewood, and Cherry. A Method for Placing Shared E-Scooters Corrals Near Transit Stops. Poster presentation at the 101st Annual Meeting of the Transportation Research Board (TRB) in Washington, DC, January 2022.

5. Shah, Ziedan, Brakewood, and Cherry. Shared e-scooter service providers with large fleet size have a competitive advantage: Findings from e-scooter demand and supply analysis of Nashville, Tennessee. Poster presentation at the 101st Annual Meeting of the Transportation Research Board (TRB) in Washington, DC, January 2022.
6. Ziedan and Brakewood. Transit Ridership in the Era of COVID-19: An Exploratory Analysis of Nationwide Trends. 2021 Research to Practice Transit Symposium, Virtual Conference, Fall 2021.

Papers:

1. Ziedan, Shah, Wen, Brakewood, Cherry, and Cole (2021). Complement or compete? The effects of shared electric scooters on bus ridership, Transportation Research Part D: Transport and Environment, Volume 101. Published as Open Access. https://doi.org/10.1016/j.trd.2021.103098
2. Ziedan, Shah, Brakewood and Cherry (2022). A Method for Placing Shared E-Scooters Corrals Near Transit Stops. Proceedings of the Annual Meeting of the Transportation Research Board, Washington, DC.
3. Under Review. Ziedan, Brakewood and Lima. A Multiple Mediation Analysis to Untangle the Impacts of COVID-19 on Nationwide Bus Ridership in the United States.
4. Under Review. Ziedan, Brakewood, and Watkins. Transit Ridership during COVID-19: An Exploratory Analysis of Nationwide Trends.
5. Under Review. Ziedan, Hightower, Brakewood and Lima. The app or cap? Which fare innovation affects bus ridership.
6. Under Review. Shah, Ziedan, Brakewood, and Cherry. Shared E-Scooter Service Providers with Large Fleet Size Have a Competitive Advantage: Findings from E-Scooter Demand and Supply Analysis of Nashville, Tennessee.

Executive Summary

Even before the onset of the COVID-19 pandemic, public transit ridership was declining in many metropolitan areas in the United States. A growing body of research has identified numerous contributing factors such as increased telecommuting, competition from transportation network companies, increases in auto availability complemented by low fuel prices, dispersion of low income population from well served transit areas, and population growth more common in geographies with less extensive transit service levels. Moreover, overall nationwide transit ridership and nationwide rail ridership hit 100-year lows in 2020 due to the COVID-19 pandemic, and nationwide bus ridership was at its lowest level in 2020 since the 1930s. It is a critical time for the public transit industry to recover in light of these recent ridership declines. To regain riders, transit agencies and their partners must make decisions about which strategies and policies to pursue within the constraints for their operating environments. Real-world, data driven research is needed to help inform transit agency decisions to win back riders.

Within this context, the Transit - Serving Communities Optimally, Responsively, and Efficiently (T-SCORE) Tier 1 University Transportation Center (UTC) was set up as a research consortium from 2020 to 2023 led by Georgia Tech (GT) that included research partners at University of Kentucky (UK), Brigham Young University (BYU) and University of Tennessee, Knoxville (UTK). The primary goal of the T-SCORE Center was to define a set of strategic visions that will guide public transportation into a sustainable and resilient future, and to equip local planners with the tools needed to translate their chosen vision into their own community. The overarching research approach for the T-SCORE Center was comprised primarily of a two-track research assessment: (1) a community analysis track (led by University of Tennessee; included in this report) and (2) a multi-modal optimization and simulation track (led by University of Kentucky; not included in this report).

This Final Report pertains to the T-SCORE Community Analysis research track, which employed a combination of quantitative and qualitative research methods to assess real-world ridership trends, identified and measured the markets most effectively served by transit, and assessed transit's ability to respond to a changing environment. The research focus was on three main drivers of change that that have affected transit ridership: price and socioeconomic factors, the competitive landscape, and system disruptions including COVID-19.

The research approach for the Community Analysis track was divided into separate projects pertaining to these key topics, and the UTK team led three of these projects, which are discussed in detail in this report. The first UTK-led project aimed to quantify the impact of different factors affecting transit ridership - including the COVID-19 pandemic - at a nationwide scale. The second UTK-led project sought to quantify the impacts of shared micromobility, particularly electric scooters, on transit ridership. The last UTK-led project aimed to evaluate new fare payment technologies and emerging pricing strategies, with the vision of taking a step toward integrating public transit into a Mobility-as-a-Service (MaaS) ecosystem.

Key Findings

Some of the key findings of the three UTK-led Community Analysis research projects are as follows:

- The first part of the research led by UTK aimed to explore the impacts of COVID-19 on ridership and recovery trends for all federally funded transit agencies in the United States from January 2020 to June 2022. The findings show that overall transit ridership hit a 100-year low in 2020. Changepoint analysis was used to show that June 2021 marked the beginning of the recovery for transit ridership in the United States. Rail and bus ridership continued to recover slowly but were still only about two-thirds of the pre-pandemic levels in most metropolitan areas by June 2022.
- To further analyze nationwide ridership trends, this research aimed to identify the direct and indirect impacts of the COVID-19 pandemic on bus ridership, where the direct impact refers to a change in travel behavior (i.e., people stop riding transit due to the increased spread of COVID-19) and the indirect impact refers to reduced ridership due to factors such as increased teleworking. A multiple mediation analysis was conducted to analyze bus ridership from March 2020 to December 2021, and the findings revealed that three mediators (employment, telework, and people relocating) mediated about 13% to 38% of the total decline in bus ridership during the analysis period.
- The next T-SCORE research project led by UTK analyzed the impacts of new micromobility modes – particularly shared electric scooters (e-scooters) – on transit ridership using Nashville, Tennessee as a case study. The results of modeling more than 1.4 million e-scooter trips suggest that on a typical weekday, utilitarian e-scooter trips are associated with a 0.94% decrease in bus ridership, whereas social e-scooter trips are associated with weekday bus ridership increases of 0.86%. A key finding is that the net effect of e-scooters on weekday bus ridership was estimated to be 0.08%, which is nearly zero.
- The T-SCORE micromobility-transit project also developed a method to identify locations to place shared e-scooter corrals near transit stops to encourage the use of shared e-scooters connecting to transit using Nashville, Tennessee as a case study. A key finding was that 50 proposed corral locations could capture about 44% of shared e-scooter demand in Nashville.
- The last UTK-led Community Analysis research project considered new fare payment technology, pricing strategies, and Mobility-as-a-Service (MaaS). One part of this project aimed to understand the impacts of mobile fare payment applications ("fare apps") and fare capping policies ("fare caps") on bus ridership. Staggered difference-in-difference techniques were used to evaluate system-level bus ridership for the 50 largest transit agencies in the United States. A key finding was that transit systems that adopted monthly fare capping policies for more than one year experienced an average increase in annual bus ridership ranging from 3.6% to 4.1%; notably, these results were heterogenous and increased over time.

Key Recommendations

- The first part of the UTK-led research analyzed nationwide ridership trends and found that transit ridership has been slow to recover from the impacts of the COVID-19 pandemic. The research identified recent service cuts due to operator shortages as a major threat to recovery. It is recommended that transit providers address this driver shortage issue as an important step toward full recovery.
- The second research project pertained to shared e-scooters and transit. One of the key results was a list of proposed e-scooter corral locations near bus stops in Nashville that could encourage e-scooter users to take the bus. The top 20 locations are included in the appendix

of this report, and it is recommended that local planners and engineers conduct an inventory of the physical characteristics of each location (e.g., size of curb space) to determine the suitably for installation of e-scooter parking infrastructure.

- Based on the results of the third part of the UTK-led T-SCORE research, the transit pricing policy known as fare capping – particularly monthly fare capping policies – could potentially increase bus ridership. Therefore, local transit agencies should consider fare capping policies if it is within the technical constraints of their existing fare collection system (e.g., electric fare collection systems).

Table of Contents

DISCLAIMER....i
Technical Report Documentation Page....ii
Acknowledgements....iii
Executive Summary....v
Key Findings....v
Key Recommendations....vi
List of Tables....x
List of Figures....xi
Glossary of Key Terms and Acronyms....xii
Chapter 1 Introduction....1
1.1 Background....1
1.2 Objectives....2
1.3 Research Approach....2
1.4 Structure of the Report....4
Chapter 2 Literature Review....5
2.1 Latest Transit Ridership Trends....5
2.2 Quantifying the Impact of New Mobility on Transit Ridership....5
2.2.1 Impacts of Micromobility on Transit Ridership....5
2.2.2 Placement of E-Scooter Infrastructure in Relation to Transit Infrastructure....6
2.3 New Fare Payments, Pricing Strategies, and Mobility-as-a-Service....6
2.3.1 Fare Capping....7
2.3.2 Mobility-as-a-Service....7
Chapter 3 Latest Analysis of Transit Ridership Trends....10
3.1 Analysis of Nationwide Ridership Trends During COVID-19....10
3.2 Analysis of Tennessee Ridership Trends During COVID-19....11
Chapter 4 The Impact of New Mobility on Ridership....13
4.1 Impact of E-Scooters on Transit Ridership in Nashville....13
4.2 Method for Placement of E-Scooters Near Transit in Nashville....13
4.3 Analysis of E-scooter Fleet Size Impacts on E-scooter Usage in Nashville....14
Chapter 5 New Fare Payments, Pricing Strategies, and Mobility-as-a-Service....16
5.1 Impacts of Fare Apps and Fare Caps on Nationwide Bus Ridership....16
5.2 The Potential for Mobility as a Service in Nashville....16

Chapter 6 Conclusion 19
6.1 Conclusions 19
6.2 Recommendations 20
6.3 Areas for Future Research 20
References 22
Appendix 1: Tennessee Transit Ridership Trends 25
Appendix 2: Proposed E-Scooter Corral Locations 31

List of Tables

Table 1: Summary of Mobility-as-a-Service Literature........ 9
Table 2: Summary of Transit Agency Operational and Policy Changes during the COVID-19 Pandemic........12
Table 3: Proposed E-Scooter Corral Locations Near Transit in Nashville........31

List of Figures

Figure 1: Annual Transit Ridership in the United States.......... 1
Figure 2: Overarching Research Approach for the T-SCORE Center.......... 3
Figure 3: Community Analysis Track Research Projects.......... 4
Figure 4: Map of Proposed Locations and Sizes of Shared E-scooter Corrals near Transit in Nashville..........14
Figure 5: Example of a Stated Preference Survey Question for a Hypothetical Mobility Bundle Choice Scenario.17
Figure 6: UPT for Demand Response Services in Tennessee..........25
Figure 7: VRM for Demand Response Services in Tennessee..........26
Figure 8: VOMS for Demand Response Services in Tennessee..........26
Figure 9: UPT for Bus Services in Tennessee..........27
Figure 10: VRM for Bus Services in Tennessee..........27
Figure 11: VOMS for Bus Services in Tennessee..........28
Figure 12: UPT for Rail Services in Tennessee..........29
Figure 13: VRM for Rail Services in Tennessee..........29
Figure 14: VOMS for Rail Services in Tennessee..........30

Glossary of Key Terms and Acronyms

- Apps: Smartphone Application
- APTA: American Public Transportation Association
- BYU: Brigham Young University
- CARTA: Chattanooga Area Regional Transportation Authority
- E-Scooters: Shared Electric Scooters
- GT: Georgia Institute of Technology / Georgia Tech
- GTFS: General Transit Feed Specification
- MaaS: Mobility-as-a-Service
- NTD: National Transit Database
- T-SCORE: Transit – Service Communities Optimally, Responsively, and Efficiently
- TCRP: Transit Cooperative Research Program
- TNCs: Transportation Network Companies
- TRB: Transportation Research Board
- UK: University of Kentucky
- UPT: Unlinked Passenger Trips
- UTC: University Transportation Center
- VOMS: Vehicles Operated in Maximum Service
- VRM: Vehicle Revenue Miles
- WeGo: WeGo Public Transit (Nashville)

Chapter 1 Introduction

1.1 Background

Even before the onset of the COVID-19 pandemic, public transit ridership was declining in many metropolitan areas in the United States. A growing body of research has identified numerous contributing factors such as increased telecommuting, competition from transportation network companies (TNCs), increases in auto availability complemented by low fuel and auto finance costs, dispersion of low income population from well served transit areas to less transit accessible environments, and population growth more common in geographies with less extensive transit service levels. The impact of COVID-19 on transit ridership was more devastating than any other prior event in the last century. Figure 1 shows nationwide ridership trends and reveals that overall transit ridership and rail ridership hit a 100-year low in 2020, while bus ridership was at its lowest level since the 1930s.

> ***Nationwide, overall transit ridership and rail ridership hit 100-year lows in 2020.***
>
> ***Bus ridership in 2020 was at the lowest level since the 1930s.***
>
> ***The transit industry is at a critical time, aiming to recover ridership.***

It is a critical time for the public transit industry, as agencies try to recover ridership. To do so, transit agencies and their partners face many challenges in deciding which of strategies and policies to pursue within the constraints for their operating environments. Real-world, data driven research is needed to help inform transit agency decisions to win back riders.

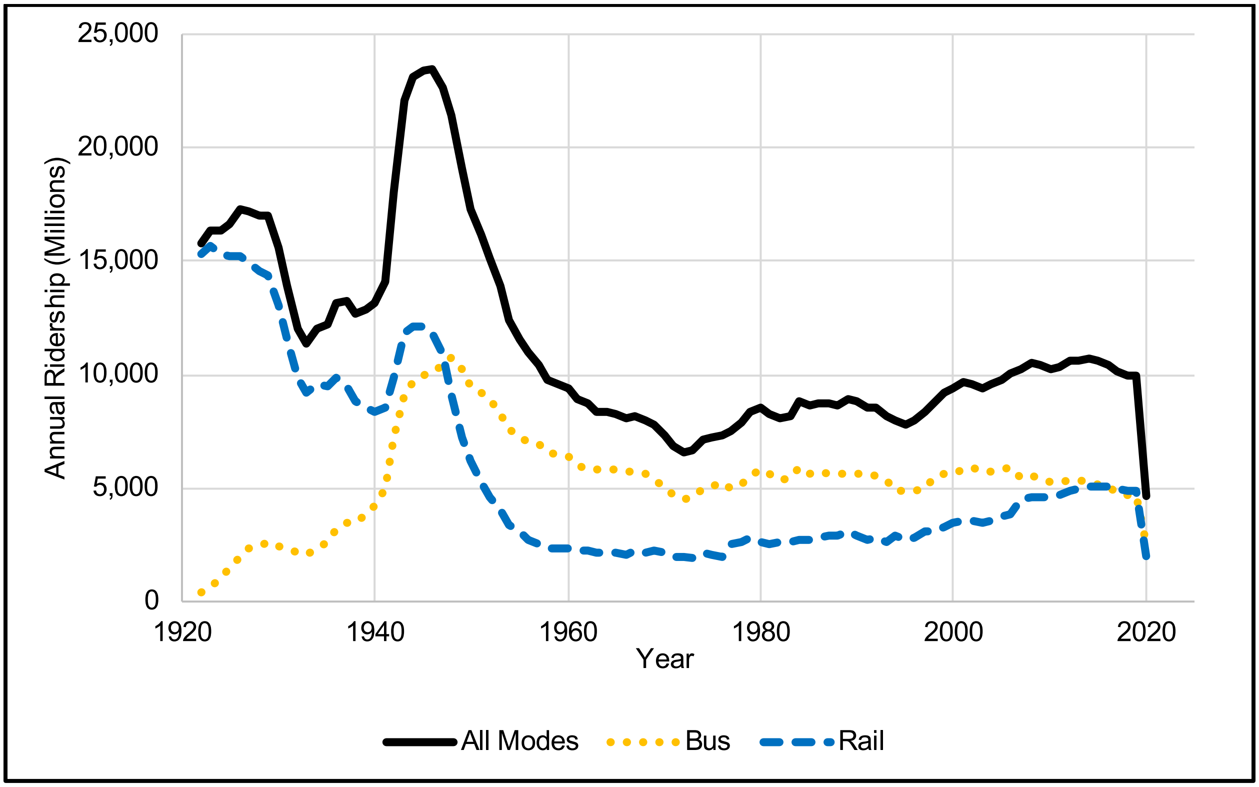

Figure 1: Annual Transit Ridership in the United States

[Data Source: National Transit Database, Figure adapted from Ziedan, 2022]

1.2 Objectives

With this context, the overarching goal of the Transit - Serving Communities Optimally, Responsively, and Efficiently (T-SCORE) University Transportation Center (UTC) was to define a set strategic visions that will guide public transportation into a sustainable and resilient future, and to equip local planners with the tools needed to translate their chosen vision into their own community.

The specific objectives of this Tennessee DOT match project were to synthesize current national ridership trends and identify strategic challenges and opportunities associated with positioning public transportation to prepare for the future. Some of the specific opportunities and challenges that were considered in this project include new fare payment technologies and pricing strategies, the potential for Mobility-as-a-Service (Maas), and integration with new micromobility modes – particularly shared electric scooters (e-scooters).

1.3 Research Approach

The T-SCORE University Transportation Center was a consortium from 2020 to 2023 led by Georgia Tech (GT) that included research partners at University of Kentucky (UK), Brigham Young University (BYU) and University of Tennessee, Knoxville (UTK). The investigators from each university are:

1. **Georgia Tech:** Dr. Kari Watkins (Center Director, now at University of California, Davis), Dr. Michael Hunter, Dr. Pascal Van Hentenryck, and Dr. Srinivas Peeta
2. **University of Kentucky:** Dr. Gregory Erhardt
3. **Brigham Young University**: Dr. Gregory Macfarlane
4. **University of Tennessee**, Knoxville: Dr. Candace Brakewood, and Dr. Christopher Cherry

The overarching research approach for the T-SCORE Center is shown in Figure 2. The research begun with the strategy generation stage, which generated qualitative descriptions of strategic directions that transit agencies and their partners can take for further evaluation. These strategic visions fed into a two-track research assessment that includes a community analysis track (led by Dr. Candace Brakewood at University of Tennessee) and a multi-modal optimization and simulation (MMOS) track (led by Dr. Greg Erhardt at University of Kentucky). Both of these tracks aimed to identify the potential feasibility, benefits, costs and implications of each strategic vision. These tracks came together in the final strategy evaluation stage, in which the findings were again considered in the context of expert advice, as shown in Figure 2. More information about the various research activities conducted as part of the UTC Tier 1 center can be found on the T-SCORE website hosted by Georgia Tech: https://tscore.gatech.edu/

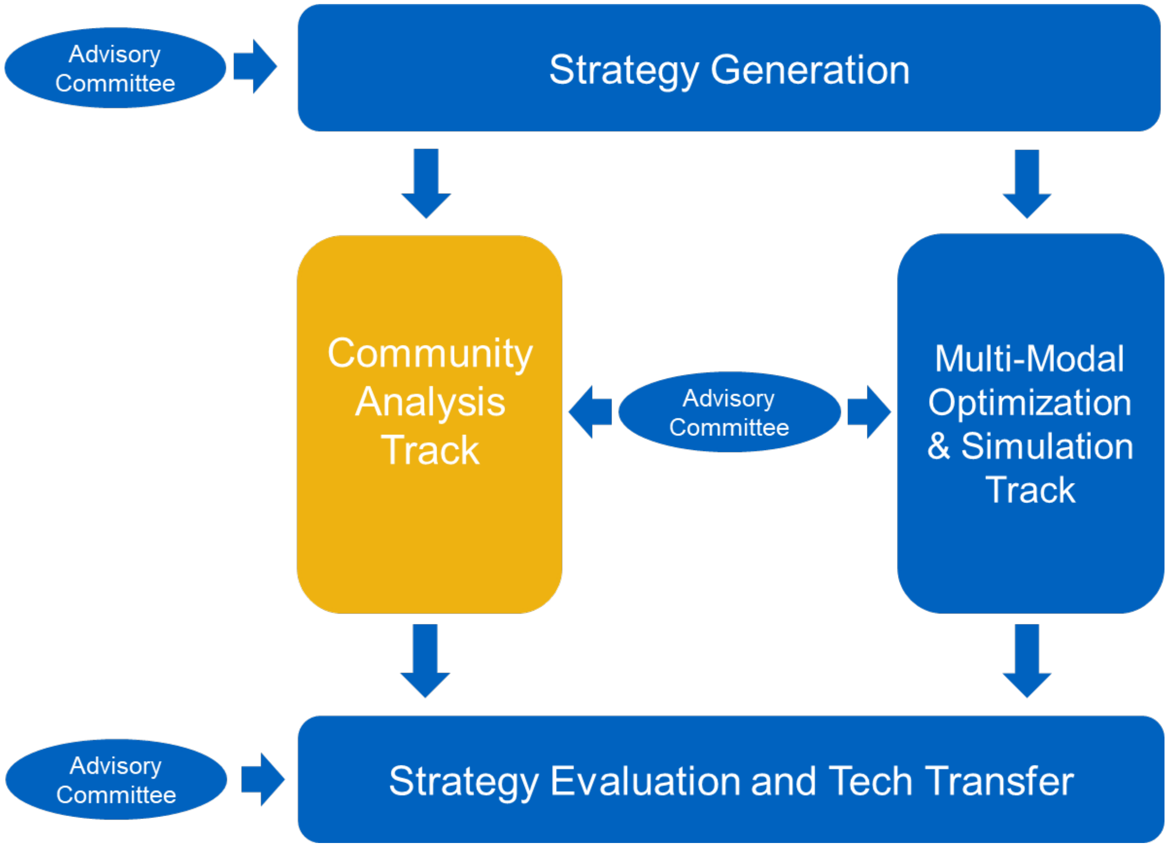

Figure 2: Overarching Research Approach for the T-SCORE Center

The focus of this Final Report is the Community Analysis research track (highlighted in yellow in Figure 2). The Community Analysis research track employed a combination of quantitative and qualitative research methods to assess real-world ridership trends, identify and measure the markets most effectively served by transit, and assess transit's ability to respond to a changing environment. The primary research area for this track was on three main drivers of change that that have affected transit ridership: *price and socioeconomic factors, the competitive landscape, and system disruptions including COVID-19*.

The Community Analysis track's research approach was divided into four separate research projects on these key topics. These four projects (numbered C1-C4) are briefly described in Figure 3. The work conducted by the University of Tennessee, Knoxville team focused on three of the four Community Analysis projects (C2, C3, and C4), which are highlighted in yellow in Figure 3. Specifically, Project C2 (*Latest National Analysis of Ridership Trends*) aimed to quantify the impact of different factors affecting transit ridership including the COVID-19 pandemic at a nationwide scale. Project C3 (*Quantifying the Impact of New Mobility on Transit Ridership*) sought to quantify the impacts of shared micromobility such as electric scooters on transit ridership. Project C4 (New Fare Payment Technology and Pricing Strategies for Mobility-as-a-Service) aimed to evaluate new fare payment technologies and emerging pricing strategies, with the vision of taking a step toward integrating transit into a mobility-as-a-service (MaaS) ecosystem. Last, it should be noted that Project C1 (*Transit Agency Short and Long-term Operational Flexibility*) is not included in this report because it was led by another T-SCORE partner university (Georgia Tech).

C1: Transit Agency Short and Long-term Operational Flexibility

- Project C1 identified and evaluated transit agencies' ability to respond to changes to the transportation system, with a focus on ability of transit agencies to adopt new mobility strategies.

C2: Latest National Analysis of Ridership Trends (included in this Report)

- Project C2 quantified the impact of different factors affecting transit ridership – including the COVID-19 pandemic – at a nationwide scale.

C3: Quantifying the Impact of New Mobility on Transit Ridership (included in this Report)

- Project C3 quantified the impacts of shared micromobility such as electric scooters on transit ridership at the metropolitan level.

C4: New Fare Payment Technology and Pricing Strategies for Mobility-as-a-Service (included in this Report)

- Project C4 evaluated new fare payment technologies and emerging pricing strategies, with the vision of taking a step toward integrating transit into a mobility-as-a-service (MaaS) ecosystem.

Figure 3: Community Analysis Track Research Projects

1.4 Structure of the Report

This report is organized as follows. Chapter 2 provides a literature review on transit ridership trends, as well as micromobility, fare pricing and Mobility-as-a-Service. Chapter 3 presents the method and the results of the first part of the research project including the latest analyses of transit ridership trends. Chapter 4 summarizes the second part of the project pertaining to new fare payments, pricing strategies, and Mobility-as-a-Service. Chapter 5 summarizes the methods and results of the third part of the project that quantifies the impact of new mobility on transit ridership. Chapter 6 includes key conclusions, areas for future research, and recommendations. Additional information is included in the Appendices.

Chapter 2 Literature Review

The literature review is divided into three parts: ridership trends; micromobility and its relation to transit; and fare pricing and Mobility-as-a-Service.

2.1 Latest Transit Ridership Trends

Numerous prior studies have analyzed transit ridership trends and the many factors that affected ridership prior to the COVID-19 pandemic (e.g., Evans, 2004; McCollom and Pratt, 2004; Taylor and Fink, 2013; Taylor and Fink, 2003; Taylor et al., 2009). One newly published Transit Cooperative Research Program (TCRP) report summarized many of the important factors affecting transit ridership in the United States prior to the pandemic (Watkins et al., 2021). In this TCRP report, the factors that affect transit were categorized into internal and external factors. Internal factors are mostly controlled by the transit agency (e.g., service quantity, fares, and service concentration), while external factors are mostly outside the agency's control (e.g., changes in population, employment, and gas prices) (Alam et al., 2018; Watkins et al., 2021).

More recently, studies have considered ridership trends in the United States in light of the COVID-19 pandemic. One relevant study of COVID-19 pandemic impacts on future transportation by USDOT explored changes in bus and rail ridership for the top transit markets in the United States from August 2019 to August 2020 using ridership data from the National Transit Database (Polzin and Choi, 2021). Another related study explored ridership changes for bus and light rail in the largest metropolitan areas in the United States from February 2020 to January 2021 (Qi et al., 2021). The results revealed that areas with higher median household incomes, higher employment rates, and higher Asian populations experienced greater ridership declines (Qi et al., 2021). Similar to the study by Polzin and Choi, Qi et al. only considered the largest metropolitan regions, leaving room for additional research on nationwide trends in the United States.

As the nation emerges out of the COVID-19 pandemic, there is a growing body of knowledge that explores various aspects of how transit ridership around the world was impacted by COVID-19. This includes international studies in China (Xin et al., 2021), Sweden (Jenelius and Cebecauer 2020), and Spain (Orro et al., 2020). In the United States, prior studies have looked at New York City (Halvorsen et al., 2021; Wang and Noland, 2021), Chicago (Hu and Chen, 2021), Nashville (Wilbur et al., 2020), Chattanooga (Wilbur et al., 2020), and North Dakota (Molina et al., 2021). However, these American studies focused on a single city or region, leaving room for additional research in the future.

2.2 Quantifying the Impact of New Mobility on Transit Ridership

This section is divided into two subsections. The first summarizes prior literature about the impact of shared electric scooters on transit ridership. The second part discusses literature about the placement of shared e-scooters in relation to transit infrastructure.

2.2.1 Impacts of Micromobility on Transit Ridership

Prior studies used two methodological approaches to assess the impact of shared e-scooters on transit. The first group of studies were user surveys conducted by municipalities where shared e-scooters operate. These surveys explored how riders are using this new mode of transportation, and a few of the most relevant results are summarized briefly here. For example, recent surveys in two different locations (Chicago, IL and Arlington, VA) revealed that 34% of respondents used e-scooters to connect to or from transit as a trip purpose and 18% of respondents used e-scooters to access transit (City of Chicago, 2020; Mobility Lab, 2019). The survey research findings seem to favor the complementary relationship between shared e-scooters and transit, which is suggested by higher percentages of survey respondents reporting that they are using shared e-scooters to connect to transit than replacing transit.

The second group of studies used empirical, econometric approaches to examine the impact of shared e-scooters on transit. Using univariate linear regression, Lu et al. found that shared e-scooters trips are positively correlated with transit trips in the city center in Austin, but negatively correlated outside of the downtown area (Lu et al., 2021). Ziedan et al found that shared e-scooters did not have a significant impact on local bus ridership, and they might have a small positive impact on express bus routes ridership in Louisville (Ziedan et al., 2021). There is room for additional research in this area, particularly in the state of Tennessee.

2.2.2 Placement of E-Scooter Infrastructure in Relation to Transit Infrastructure

This section discusses prior studies that explored shared e-scooter parking locations or developed methods to locate shared e-scooter parking facilities. In Louisville, Kentucky, a prior study evaluated half a million shared e-scooter trips to explore if shared e-scooters are parked near bus stops (Abouelela et al., 2021). Abouelela et al. found on average, shared e-scooters are parked 115 meters from the nearest bus stop, and 85% of the shared e-scooters trips ended within 200 meters of the nearest bus stop (Abouelela et al., 2021).

In Madrid, Spain, a 2021 study used Geographic Information System location-allocation models and moped-style scooter sharing trip data to propose parking locations (Pérez-Fernández et al., 2021). Candidate locations were defined based on the number of trips started or ended in a 50m x 50m grid. This prior study also imposed a minimum distance of 200m between the proposed parking locations and found that 200 parking locations covered 72% of the demand.

Another relevant prior study in Nashville, Tennessee proposed ways to locate shared e-scooter parking facilities using historical trip data of operators (Sandoval et al., 2021). The prior study used various algorithms to select areas that show high demand for shared e-scooter parking. The study showed that the proposed parking locations at Vanderbilt University could capture 25% of shared e-scooters demand. In summary, the prior studies of Madrid and Nashville proposed methods to locate shared e-scooter parking facilities by focusing on the total demand of shared e-scooters but did not consider how e-scooter parking infrastructure interacts with transit. Therefore, there is room for additional research to specifically focus on integration of e-scooter infrastructure with public transit.

2.3 New Fare Payments, Pricing Strategies, and Mobility-as-a-Service

This section is divided into two subsections: the first part summarizes the literature on the new pricing strategy known as fare capping, and the second part discusses literature about Mobility-as-a-Service (MaaS).

2.3.1 Fare Capping

Changes to fare policy in response to electronic payment innovation and the need for equitable fare structures have been explored in numerous prior studies, including numerous references from the Transit Cooperative Research Program (TCRP) of the Transportation Research Board. This review focuses specifically on fare capping, which is a pricing policy in which a transit agency caps the maximum amount a rider pays over a given period, which has emerged as a relatively new innovation in the transit industry.

***Fare capping** is a pricing policy in which a transit agency caps the maximum amount a rider pays over a given period (e.g., one day, one week, or one*

Perhaps the most relevant reference is a newly published TCRP synthesis that specifically aimed to understand transit agency motivations to implement fare capping and assess the effect of fare capping policies on revenue and ridership (Pettine, 2021). This TCRP synthesis focused on implementation, planning, and assessment of fare capping from the perspective of a transit agency.

A few other studies of fare capping have focused on international examples. One previous study proposed a fare engine for Transport for London that simplified riders' experience by using fare capping to guarantee the best fare (Lau, 2009). In another prior study, the revenue changes due to various fare capping periods were explored through simulated scenarios using automated fare collection data for Montreal, Canada. The results suggested that an increase in fare revenue could be expected with only daily, or daily and weekly fare capping, and the study concluded that a rider may be less incentivized for additional trips before reaching the cap, and more incentivized to make trips after (Chu et al., 2019). A third international study of Australia and New Zealand summarized what type of fare capping policies were offered by local transit authorities and found that, out of 27 transit agencies, six agencies offered a daily cap, four agencies offered a weekly cap, and only one agency offered a monthly cap (Chalabianlou et al., 2015). This study also suggested that rider incentives to travel might be greater when fare caps are applied over shorter time periods because a smaller number of trips are required to reach a cap.

In conclusion, there is room for additional research on fare capping, particularly the impacts on transit ridership in the United States.

2.3.2 Mobility-as-a-Service

***Mobility-as-a-Service** can be defined as a combination of mobility options presented in a single programmed mobility platform (e.g., on a smartphone app), with public transit typically being the main focus.*

Mobility-as-a-Service (MaaS) is a combination of mobility options presented in a single programmed mobility platform, with public transportation typically being the main focus (APTA, 2019). One relevant study on MaaS was a 2019 mission to Europe by the American Public Transportation Association (APTA) to study the implementation of MaaS. Key findings from Europe suggest that MaaS can reduce reliance on single occupancy vehicles, and that public transportation was the backbone of MaaS solutions. Additionally, a sustainable mobility vision, a well-integrated system, and cooperation among mobility partners were vital components of a MaaS system (APTA, 2019).

Several publications have detailed the necessary components of a MaaS business model. A 2020 study designed a business template with which a MaaS platform may reach its full potential. The role of a public transportation authority was critical to the implementation of MaaS in Europe, whereas in the United States, mobility service providers were identified as having a more critical role. Additional components of the business model include payments, customer relationships, advertisement, and investment cost structure (Polydoropoulou et al., 2020). Prior research has also proposed models describing different levels of integration of MaaS ecosystems. For example, a 2016 report by Kamargianni et al. identified ticketing, payments, mobility packages, and information and communications technology as the basic parameters of a MaaS integration (Kamargianni et al., 2016). A 2019 study by Lyons et al. created a *Levels of MaaS Integration* taxonomy specifically for a user looking for an alternative to a private vehicle; full integration was defined as seamless door-to-door experience with the same convenience as private vehicles (Lyons et al., 2019).

MaaS options are often presented as "bundles" including different transportation services and prices. A synthesis of MaaS "bundle" dimensions was developed by Reck et al. in 2020. The five necessary design dimensions identified were the included modes, the metric to measure consumption, the geographical service area, the market segment, and the length of the subscription cycle. Researchers noted that when users pay per use, the inclusion of more modes may increase the value of the MaaS integration, whereas willingness to pay a subscription to the overall bundle may decrease if the bundle is not customizable. However, there could be a positive relationship between the number of modes in the integration and the cost and complexity of the software development when differences exist between each mode's application programming interface (Reck et al., 2020). Last, an overarching framework has recently been created by the United Nations Economic Commission for Europe (UNECE), and by Hensher et al. in their book *Understanding Mobility as a Service (MaaS): Past, Present, and Future* (UNECE, 2020; APTA, 2019; Sochor et al., 2018). These frameworks include payment integration and roles that a MaaS provider may take.

Nearly all prior research discussed here and summarized in Table 1 (see next page) focuses on Europe, and there is limited if any literature from the United States pertaining to MaaS business models, levels of integration, and bundles evaluated using survey methods.

Table 1: Summary of Mobility-as-a-Service Literature

Year	Title	Author(s)	Key Findings
2014	Challenges in Integrating User, Commercial, and Societal Perspectives in an Innovative Mobility Service	Sochor, Strömberg, Karlsson	93% of participants were satisfied with their travel, and 97% wanted to continue using the MaaS system.
2016	A Critical Review of New Mobility Services for Urban Transport	Kamargianni, Li, Matyas, Schäfer	Four Integration Types: 1) Ticket, 2) Payment, 3) ICT, 4) Mobility Package
2019	The Importance of User Perspective in the Evolution of MaaS	Lyons, Hammond, Mackay	Six taxonomies: 1) Level 0 – no integration, 2) Level 1 – information integration, 3) Level 2 – information integration with payment options for some modes, 4) Level 3 – full integration for some travel modes, 5) Level 4 – full integration for some combinations of travel modes, and 6) Level 5 – full integration for all travel conditions.
2019	Being Mobility-as-a-Service (MaaS) Ready	American Public Transportation Association	1) MaaS is an opportunity to reduce reliance on single occupancy vehicles for the improvement of the economy, environment, and society. 2) "Mobility hubs" are being developed as an important physical part of a MaaS system. 3) Public transportation must be the backbone of MaaS in order to look out for public interest and provide a complete mobility solution. 4) Technology is outpacing governance solutions and therefore, governance is a key challenge in the implementation of MaaS. 5) Public transportation agencies need to understand the value and leverage of their own infrastructure and data as well as allow for more innovation and experimentation.
2020	MaaS Bundle Design	Reck, Hensher, Ho	Ten fundamental design dimensions make up a framework by which a MaaS integration may be compared or developed: 1) modes, 2) consumption metric, 3) geographic area, 4) market segment, 5) subscription cycle, 6) discounts, 7) caps, 8) add-ons, 9) customizability, 10) credit roll-over.
2020	Prototype Business Models for Mobility-as-a-Service	Polydoropoulou, Pagoni, Tsirimpa, Roumboutsos, Kamargianni, Tsouros	Nine common factors drive the success of a MaaS implementation.

Chapter 3 Latest Analysis of Transit Ridership Trends

The first of the T-SCORE Community Analysis research projects led by the University of Tennessee analyzed the latest in transit ridership trends both across the United States and locally in Tennessee using publicly available data from the National Transit Database (NTD). The research was divided into two primary subtasks that are summarized in the following paragraphs. The first subtask focused on nationwide trends, and the second specifically considered ridership trends in Tennessee. Ridership data both before and during the COVID-19 pandemic were included in these analyses.

3.1 Analysis of Nationwide Ridership Trends During COVID-19

Summary: Although the COVID-19 pandemic highly impacted transit ridership as people reduced or stopped travel, these changes occurred at different rates in different regions. The first part of this research aimed to explore the impacts of COVID-19 on ridership and recovery trends for all federally funded transit agencies in the United States from January 2020 to June 2022. The findings show that overall transit ridership hit a 100-year low in 2020. Changepoint analysis was used to show that June 2021 marks the beginning of the recovery for transit ridership in the United States. Rail and bus ridership continued to recover slowly but were still only about two-thirds of the pre-pandemic levels in most metropolitan statistical areas (MSAs) by June 2022. In a handful of MSAs like Tampa and Tucson, rail ridership has reached or exceeded 2019 ridership. This research also discusses some long-term changes, including increased telecommuting and operator shortages as well as some new opportunities that emerged, such as zero fares and increased availability of bus lanes. The findings can help inform agencies about their performance compared to their peers and highlight general challenges facing the transit industry over the coming decade.

To further analyze nationwide ridership trends, the second part of this research specifically aimed to identify the direct and indirect impacts of the COVID-19 pandemic on bus ridership. In the context of this research, the direct impact refers to a change in travel behavior (i.e., people stop riding transit due to the increased spread of COVID-19), while the indirect impact refers to reduced ridership due to factors such as lower employment or increased teleworking. This research proposed a framework to explore the drivers of transit ridership declines during COVID-19. The method is a multiple mediation analysis to estimate the monthly direct and indirect impacts of COVID-19 on bus ridership from March 2020 to December 2021. The results revealed that three mediators (employment, telework, and people relocating) mediated about 13% to 38% of the total decline in bus ridership during the analysis period. The multiple mediation approach used in this study could be applied in many other transportation applications.

Publications: Two journal papers that contain the detailed methodology and results are currently under review. Preprint versions of both papers can be found in the University of Tennessee PhD dissertation of the lead author (Ziedan, 2022). The suggested citations are as follows:

Ziedan, Brakewood, and Watkins, Will transit recover? A retrospective study of nationwide ridership in the United States during the COVID-19 pandemic. Under review in the *Journal of Public Transportation.*

Ziedan, Lima, and Brakewood, A Multiple Mediation Analysis to Untangle the Impacts of COVID-19 on Nationwide Bus Ridership in the United States. Under Review in *Transportation Research Part A: Policy and Practice*.

3.2 Analysis of Tennessee Ridership Trends During COVID-19

Summary: This research project considered changes in operations, policies, and ridership of transit agencies in Tennessee due to COVID-19. Many short-term changes were made during 2020 and 2021 to keep riders and staff safe from the spread of COVID-19. This research specifically considered seven categories of operational and policy changes, which were as follows: [1] Passenger/ Trip Restrictions, [2] Capacity, [3] Sanitation, [4] Fares, [5] Service Changes, [6] Staffing/ Funding, and [7] Role Expansion. Information about these seven categories was compiled from publicly available sources, such as transit agency websites, reports, and news archives, for the four largest agencies in Tennessee: Chattanooga Area Regional Transit Authority (CARTA), Knoxville Area Transit (KAT), Memphis Area Transit Authority (MATA), and Nashville's WeGo Public Transit (WeGo). A summary of the findings is shown in Table 2. In addition, monthly ridership data were analyzed for all transit agencies in Tennessee. The National Transit Database's monthly module adjusted data release was used to analyze unlinked passenger trips (UPT), vehicle revenue miles (VRM), and vehicles operated in maximum service (VOMS). This data was analyzed for demand response, bus, and rail for the transit agencies in Tennessee from January 2018 to December 2021, and the detailed ridership analysis results can be found in Appendix 1.

Table 2: Summary of Transit Agency Operational and Policy Changes during the COVID-19 Pandemic

	CARTA (Chattanooga)	**KAT (Knoxville)**	**MATA (Memphis)**	**WeGo (Nashville)**
Passenger/ Trip Restrictions	• Masks required • Board through rear door *(a)*	• Masks required • Board through rear door • Essential trips only *(g)*	• Board through rear door • Essential trips only *(i)*	• Masks required • Board through rear door • Essential trips only *(n)*
Capacity	• Limit ten passengers per bus *(b)*	• Reduced capacity to 50% *(g)*	• Limit ten passengers per bus *(j,k);* MATAplus: limit two passengers *(k)*	• No public information available
Sanitation	• Cleaned and disinfected daily • Masks provided *(c)*	• Disinfected daily • Sanitizer and masks provided *(g)*	• No public information available	• Disinfect between stops *(n)*
Fares	• Fare free: August '20 – August '21 *(d)*	• Fare free: March '20 • Reduced fares: Feb '21 *(g, h)*	• Fare free: March – June '20 *(j)*	• Fare free: May – Sept '20 *(p)*
Service Changes	• No public information available	• Weekday service reduction *(g)*	• MATAplus service for work, medical, and food services only *(l)*	• Increase the number of trips during peak hours *(p)*
Staffing/ Funding	• Additional buses due to capacity restrictions • CARES: $11.9 million *(b, e)*	• Workforce shortage due to employees following CDC guidelines (g)	• CARES: $36 million *(m)*	• CARES: $55.1 million *(q)*
Role Expansion	• Care-A-Van additional services *(f)*	• No public information available	• No public information available	• No public information available

Sources:
(a) https://web.archive.org/web/20210117061402/https://www.gocarta.org/news/covid-updates/
(b) https://web.archive.org/web/20200507134240/http://www.gocarta.org:80/
(c) https://web.archive.org/web/20200811094315/https://www.gocarta.org/
(d) https://web.archive.org/web/20210505222824/https://www.gocarta.org/news/covid-updates
(e) http://www.chattanoogapulse.com/local-news/carta-receives-11-9-million-grant-from-federal-government/
(f) https://newschannel9.com/news/local/care-a-van-helping-get-supplies-to-chattanooga-seniors-people-with-disabilities
(g) https://www.katbus.com/Blog.aspx?IID=63&ARC=131
(h) https://www.katbus.com/Blog.aspx?IID=65&ARC=132
(i) https://www.matatransit.com/assets/2/15/Civil_Emergency_Proclamation_3-23.pdf?458
(j)
https://www.matatransit.com/assets/2/15/Additional_Buses_Added_To_Lessen_Wait_Times_At_Bus_Stops_and_Shelters_03312020.pdf?453
(k) https://www.matatransit.com/assets/2/15/MATA_Announces_Immediate_Social_Distancing_Measures_03212020.pdf?461
https://www.matatransit.com/assets/2/15/UPDATE_Service_Changes_In_Response_To_COVID-19.pdf?455
(m) https://www.matatransit.com/assets/2/15/Statement_from_MATA_CEO_Gary_Rosenfeld_Regarding_COVID-19_Stimulus_Funds.pdf?451
(n) https://www.wegotransit.com/assets/1/17/news1053.pdf?327
(p) https://www.wegotransit.com/assets/1/17/news1070.pdf?342
(q) https://www.wegotransit.com/assets/1/17/news1064.pdf?336

Chapter 4 The Impact of New Mobility on Ridership

The second T-SCORE Community Analysis research project led by the University of Tennessee analyzed the impacts of new mobility modes – particularly micromobility – on transit ridership. Micromobility includes modes such as bicycles, electric bicycles (e-bikes), and electric scooters (e-scooters). This research focused specifically on shared electric scooters (e-scooters) in Nashville, Tennessee, because of the availability of detailed e-scooter trip and device location data that were obtained through a data request to Nashville's Metropolitan Planning Organization (MPO). The research was divided into three primary subtasks that are summarized in the following paragraphs.

4.1 Impact of E-Scooters on Transit Ridership in Nashville

Summary: The rapid onset of shared electric scooters (e-scooters) has raised questions about their effects on other transportation modes, particularly sustainable modes such as transit. Existing literature concerning the impacts of e-scooters on transit ridership showed that e-scooters could both compete with or complement transit. However, prior studies did not differentiate by e-scooter trip purpose. This study aims to fill this gap using Nashville, Tennessee, as a case study. The results of modeling more than 1.4 million e-scooter trips suggest that on a typical weekday, utilitarian e-scooter trips are associated with a 0.94% decrease in bus ridership. However, social e-scooter trips are associated with weekday bus ridership increases of 0.86%. The net effect of e-scooters on weekday bus ridership is estimated to be 0.08%, which is nearly zero. These findings can help inform city planners as they integrate micromobility into urban transportation systems.

Publication: An open access journal paper contains the detailed methodology and results; the suggested citation and link to the open access paper are as follows:

> Ziedan, Shah, Wen, Brakewood, Cherry, and Cole (2021). Complement or compete? The effects of shared electric scooters on bus ridership, *Transportation Research Part D: Transport and Environment*, Volume 101. https://doi.org/10.1016/j.trd.2021.103098

4.2 Method for Placement of E-Scooters Near Transit in Nashville

Summary: The rapid adoption of shared e-scooters has created different challenges for cities, including the management of shared e-scooter parking. However, shared e-scooters have the potential to improve accessibility in cities as first/last-mile connections to transit. Some prior studies have proposed solutions to the parking issue, while others have proposed approaches to use e-scooters as first/last-mile connections. However, few prior studies have addressed these two aspects together, which is the focus of this analysis. This study proposed a mixed methods approach to select locations to place shared e-scooter corrals near transit stops to encourage the use of shared e-scooters connecting to transit using Nashville, Tennessee, as a case study. The method first used supervised machine learning to identify shared e-scooters trips that complement transit. Then, a multi-criteria scoring system was applied to rank bus stops based on shared e-scooter activity and bus service characteristics. Based on this scoring system, bus stops with the 50 highest scores were selected as potential locations for shared e-scooter corrals (see Figure 4; a list of the top 20 bus stop locations for potential e-scooter corrals is found in Appendix 2, and the full list of 50 is available upon request from the authors). Then, the capacity for the potential parking locations was estimated based on the hourly shared e-scooter usage. The results suggest that the 50 proposed corral locations could capture about 44% of shared e-scooter demand. The findings of this study could guide the implementation of shared e-scooter corrals in Nashville and inform other cities about how to select locations for shared e-scooter corrals near transit.

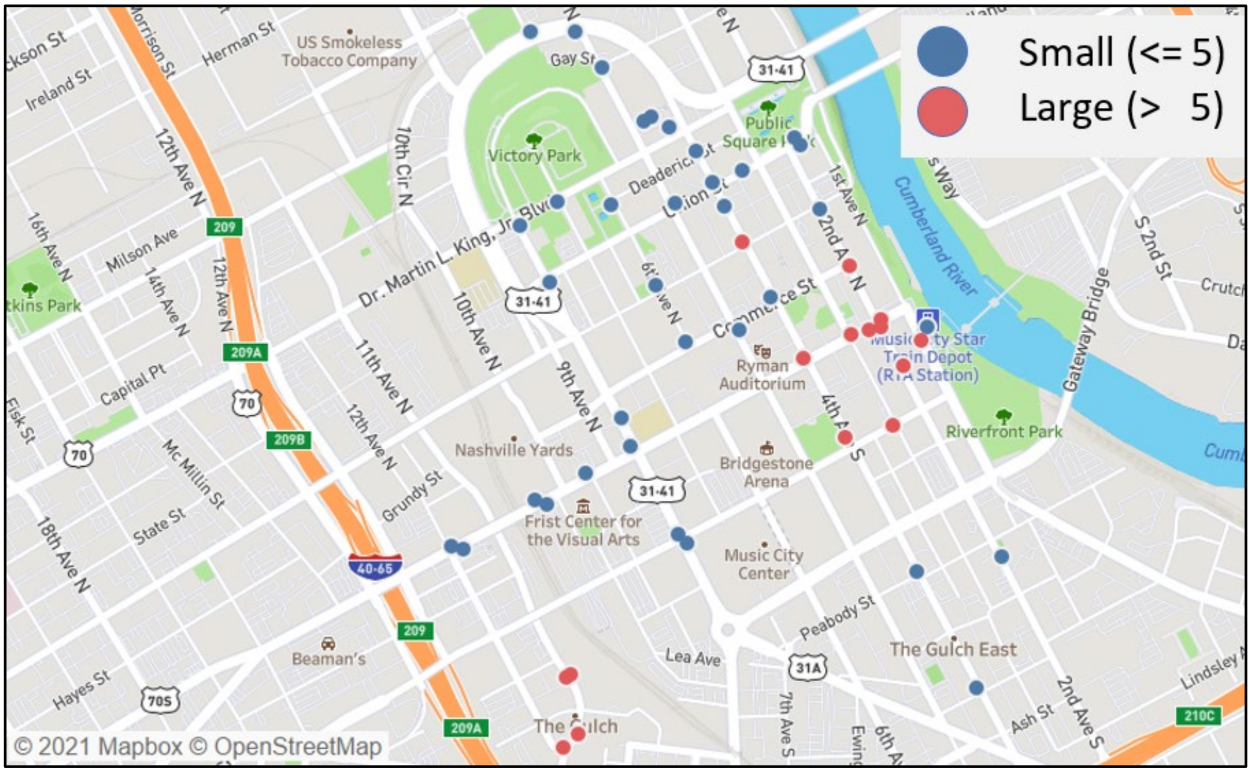

Figure 4: Map of Proposed Locations and Sizes of Shared E-scooter Corrals near Transit in Nashville

Publication: A paper containing the detailed methodology and results were published in 2022 Compendium of the Annual Meeting of the Transportation Research Board. The suggested citation and link to the full manuscript are as follows:

> Ziedan, Shah, Brakewood, and Cherry (2022), A Method for Placing Shared E-Scooters Corrals Near Transit Stops. Proceedings of the Transportation Research Board 101st Annual Meeting, Washington DC. Available at SSRN: https://dx.doi.org/10.2139/ssrn.4167543

4.3 Analysis of E-scooter Fleet Size Impacts on E-scooter Usage in Nashville

Summary: Shared e-scooter systems are one of the fastest-growing micromobility modes in the United States. In response to service providers' rapid deployment of e-scooter vehicles, several city governments have regulated shared e-scooters through permits and pilot programs, including the number of service providers, their fleet size, and provisions for expanding/downsizing the fleet size. However, the literature lacks an empirical analysis of the demand elasticity of shared e-scooters. We used a negative binomial fixed effect regression to evaluate the demand elasticity of e-scooter vehicle deployment using the Shared Urban Mobility Device (SUMD) dataset from Nashville, Tennessee, between April 2019 and February 2020. This dataset included disaggregated e-scooter trip summary data and vehicle location data that updates approximately every five minutes. We also estimated land-use specific demand elasticity of e-scooter vehicle deployment by clustering Traffic Analysis Zones (TAZs) using the K-means algorithm. We found that the average daily demand elasticity of e-scooter vehicle deployment is inelastic (0.55). Service providers with large fleet sizes (>500) have a demand elasticity of e-scooter deployment that is 2.5 times higher than that of medium fleet-sized service providers (250-500). We also found a significant difference in demand elasticity of e-scooter deployment for land use types, with university and park and waterfront land uses having the highest elasticity values. These findings could be helpful for city governments to identify the optimal number of service providers and fleet sizes to permit so that demand is fulfilled without an oversupply of e-scooter vehicles in public spaces.

Publication: An open access paper containing the detailed methodology and results in preprint (unpublished) form can be found through the Social Science Research Network (SSRN). The suggested citation and link to the full manuscript are as follows:

> Shah, Ziedan, Brakewood, and Cherry, Shared E-Scooter Service Providers with Large Fleet Size Have a Competitive Advantage: Findings from E-Scooter Demand and Supply Analysis of Nashville, Tennessee. Available at SSRN: https://dx.doi.org/10.2139/ssrn.4167543

Additional Acknowledgment: This research on e-scooter fleet size was also supported in part by the Oak Ridge National Laboratory Graduate Advancement, Training, and Education (GATE) fellowship program.

Chapter 5 New Fare Payments, Pricing Strategies, and Mobility-as-a-Service

The last T-SCORE Community Analysis research project led by the University of Tennessee considered new fare payment technology, pricing strategies, and Mobility-as-a-Service (MaaS). The research was divided into two primary subtasks that are summarized in the following paragraphs. The first subtask aimed to quantify the impacts of mobile fare payment applications ("fare apps") and fare capping ("fare caps") pricing policies on bus ridership for operators across the country. The second subtask considered hypothetical possibilities for future MaaS implementation in Nashville, TN.

5.1 Impacts of Fare Apps and Fare Caps on Nationwide Bus Ridership

Summary: Technology advancements in the last two decades have changed several aspects of public transit service, particularly related to fares. Transit agencies seek to benefit from these technologies to improve the customer experience by launching mobile fare payment applications ("apps") and adopting more sophisticated fare policies such as fare capping ("caps"). However, there is a limited understanding of the impacts of these two fare innovations on bus ridership. Therefore, this research seeks to understand the impacts of mobile fare payment applications and fare capping policies (both daily and monthly) on bus ridership. Staggered difference-in-difference techniques were used to evaluate system-level bus ridership for the 50 largest transit agencies in the United States. This approach considers the effect on multiple treated units that adopted apps or caps at different times; it also considers the heterogeneity of the treatment effect between treated units and over time. The results suggest that the launch of mobile fare payment applications and the adoption of daily fare capping policies did not have significant impacts on system-level ridership. On the other hand, monthly fare capping policies were associated with significant ridership gains. Transit systems that adopted monthly fare capping policies for more than one year experienced an average increase in annual bus ridership ranging from 3.6% to 4.1%; these results were heterogenous and increased over time. These findings can help to inform transit agencies across the United States as they consider different strategies to increase ridership and reverse recent bus ridership declines. Perhaps most important, the staggered difference-in-difference methodology could potentially be applied to evaluate a wide range of transportation technology and policy innovations with staggered (gradual) rollouts.

Publications: A journal paper that contains the detailed methodology and results is currently under review. A preprint version of this paper can be found in the University of Tennessee PhD dissertation of the lead author (Ziedan, 2022). The suggested citation is as follows:

> Ziedan, Hightower, Lima and Brakewood, The app or the cap? Which fare innovation affects bus ridership? Under review in *Transport Policy.*

5.2 The Potential for Mobility as a Service in Nashville

Summary: Mobility-as-a-Service (MaaS) is a combination of mobility options presented in a single programmed mobility platform, with public transportation typically being the main focus (APTA, 2019). MaaS options are often presented as "bundles" including different transportation services and prices. Bundling has existed in many areas, including telecommunications, media subscription services, and tourism (e.g., flight, hotel, car rental, and excursions). The introduction of new shared and micromobility modes (e.g., shared e-scooters, bikeshare, and TNCs) in many urban areas has led to discussion about integration of public transit with these new modes in the form of mobility plan, and configuration of potential MaaS "bundles" has become a topic of interest to transportation researchers and practitioners. In this research, hypothetical mobility plans for a stated preference experiment were designed specifically for the transportation services available in Nashville.

Statistically, the mobility bundles were constructed in an orthogonal fractional factorial design, pivoting around the survey respondent's reported information for the ability to ride a bicycle and for having a driving license to create real choice situations. Consequently, the design is orthogonal in attribute differences, with the main potential advantages of equidistant coverage of attribute space and attribute level balance. Four orthogonal designs were developed. The first design comprised all transportation modes (e.g., transit, bikeshare, shared e-scooters, car sharing, car rental, TNCs; see Figure 5). This design strategy resulted in 192 profiles blocked into 16 orthogonal subsets. The second design excludes the bike share mode and leads to 60 profiles blocked into five orthogonal subsets. The third design excludes the car share options, which led to 48 profiles that were blocked into four orthogonal subsets. Finally, the fourth design excludes both the car share and bike share resulting in 60 profiles that were blocked into five orthogonal subsets. Each orthogonal subset included twelve choice sets, presented to each respondent as three choices per question. This stated preference experiment was conducted via an online survey that was distributed to transit riders in Nashville in January 2023.

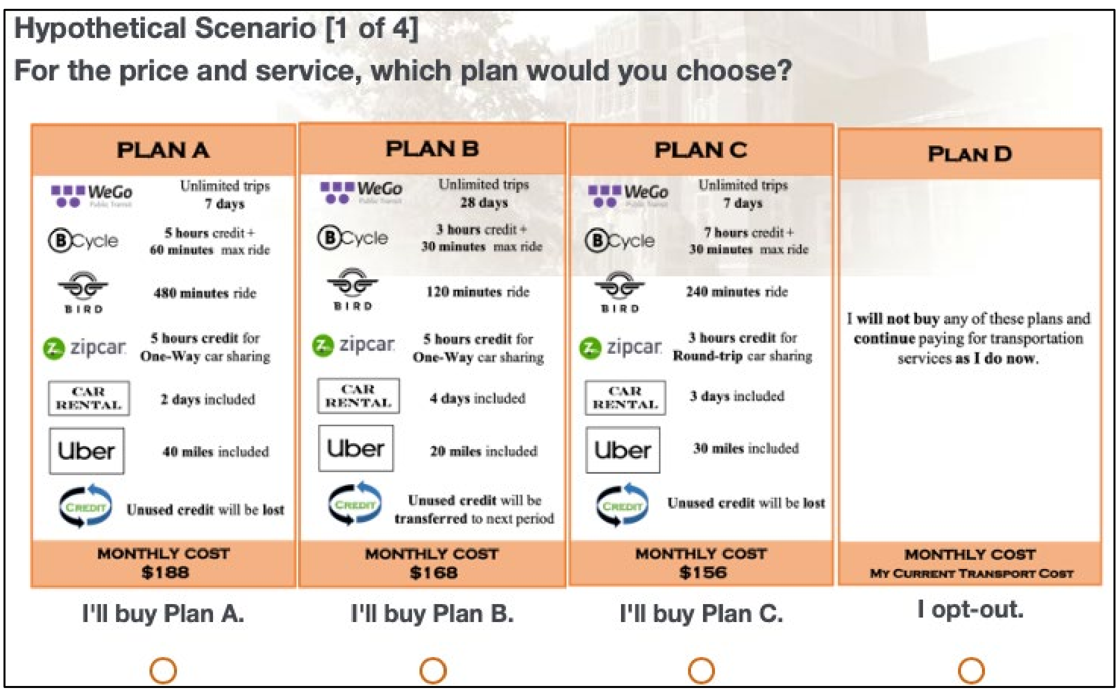

Figure 5: Example of a Stated Preference Survey Question for a Hypothetical Mobility Bundle Choice Scenario

<u>Publications:</u> A paper that contains the detailed methodology and results is currently in preparation for submission to a journal.

Chapter 6 Conclusion

This chapter presents conclusions, areas for future research, and recommendations based on the research findings.

6.1 Conclusions

This section presents a brief summary of the key findings and conclusions from this research.

- The first part of the T-SCORE research led by UTK aimed to explore the impacts of COVID-19 on ridership and recovery trends for all federally funded transit agencies in the United States from January 2020 to June 2022. The findings show that overall transit ridership hit a 100-year low in 2020. Changepoint analysis was used to show that June 2021 marked the beginning of the recovery for transit ridership in the United States. Rail and bus ridership continued to recover slowly but were still only about two-thirds of the pre-pandemic levels in most metropolitan statistical areas (MSAs) by June 2022.
- To further analyze nationwide ridership trends, this research also aimed to identify the direct and indirect impacts of the COVID-19 pandemic on bus ridership, where the direct impact refers to a change in travel behavior (i.e., people stop riding transit due to the increased spread of COVID-19) and the indirect impact refers to reduced ridership due to factors such as lower employment or increased teleworking. A multiple mediation analysis was conducted to analyze bus ridership from March 2020 to December 2021, and the findings revealed that three mediators (employment, telework, and people relocating) mediated about 13% to 38% of the total decline in bus ridership during the analysis period.
- The next T-SCORE research project led by the University of Tennessee analyzed the impacts of new micromobility modes – particularly shared electric scooters (e-scooters) – on transit ridership using Nashville, Tennessee, as a case study. The results of modeling more than 1.4 million e-scooter trips suggest that on a typical weekday, utilitarian e-scooter trips are associated with a 0.94% decrease in bus ridership, whereas social e-scooter trips are associated with weekday bus ridership increases of 0.86%. A key finding is that the net effect of e-scooters on weekday bus ridership was estimated to be 0.08%, which is nearly zero.
- The T-SCORE micromobility-transit project also developed a method to identify locations to place shared e-scooter corrals near transit stops to encourage the use of shared e-scooters connecting to transit using Nashville, Tennessee, as a case study. A key finding was that 50 proposed corral locations could capture about 44% of shared e-scooter demand in Nashville.
- The last T-SCORE Community Analysis research project led by the University of Tennessee considered new fare payment technology, pricing strategies, and Mobility-as-a-Service (MaaS). One part of this project aimed to understand the impacts of mobile fare payment applications (“fare apps”) and fare capping policies (“fare caps”) on bus ridership. Staggered difference-in-difference techniques were used to evaluate system-level bus ridership for the 50 largest transit agencies in the United States. A key finding was that transit systems that adopted monthly fare capping policies for more than one year experienced an average increase in annual bus ridership ranging from 3.6% to 4.1%; notably, these results were heterogenous and increased over time.

6.2 Recommendations

This section presents three recommendations based on each of the T-SCORE research projects.

- The first part of the UTK-led T-SCORE research analyzed nationwide ridership trends and found that transit ridership has been slow to recover from the impacts of the COVID-19 pandemic, and as of June 2022, it was still about one-third below the 2019 levels. The research identified recent service cuts due to operator shortages as a major threat to recovery. It is recommended that transit providers address this driver shortage issue as a major step toward full recovery.
- The second research project pertained to shared e-scooters and transit. One of the key results was a list of 50 proposed e-scooter corral locations near bus stops in Nashville that could encourage e-scooter users to take the bus. The top 20 locations are included in Appendix 2 of this report, and it is recommended that local planners and engineers conduct an inventory of the physical characteristics of each location (e.g., size of curb space) to determine the suitably for e-scooter parking infrastructure.
- Based on the results of the third part of the research project, the transit pricing policy known as fare capping – particularly monthly fare capping policies – could potentially increase bus ridership. Therefore, local transit agencies should consider fare capping policies if it is within the technical constraints of their existing fare collection system (e.g., electric fare collection systems). It should be noted WeGo Transit in Nashville recently implemented both daily and monthly fare capping.

6.3 Areas for Future Research

Some key areas for future research are discussed in the following paragraphs.

- The first of the UTK-led T-SCORE Community Analysis research projects focused on nationwide ridership trends, particularly during COVID-19. However, other impacts on the transit industry emerged from the pandemic, such as impacts on transit revenue and funding, which are important areas for future research.
- The second part of the UTK-led T-SCORE research focused on the relationship between shared e-scooters and transit using Nashville as a case study, largely because of the availability of detailed shared e-scooter data. However, Nashville may not represent other cities in Tennessee or the United States due to differences in transportation systems and travel behavior. Therefore, further analysis of the relationship between shared e-scooters and transit use is needed in other locations if e-scooter data becomes available.
- The last part of the research pertaining to fare pricing revealed that the adoption of daily fare capping policies did not have significant impacts on annual bus ridership, whereas monthly fare capping policies were associated with significant gains in system-level annual bus ridership. It is possible that the impact of daily capping might be short term and potentially could not be captured in an annual model; therefore, future research is needed at a more granular level to better assess the impacts of daily and/or weekly fare capping policies on ridership.

References

1. Abouelela, Mohamed, Christelle Al Haddad, and Constantinos Antoniou. "Are e-Scooters Parked Near Bus Stops? Findings from Louisville, Kentucky." Findings (2021): 29001.
2. Alam, B.M., Nixon, H., Zhang, Q., (2018) Factors Affecting Travel Demand by Bus: An Emiprical Analysis at Us Metropolitan Statistical Area Level. *Transportation Research Record,* 2672, pp. 817-826.
3. American Public Transportation Association. *Being Mobility-as-a-Service (MaaS) Ready*. Washington, D.C., 2019.
4. Chalabianlou, R., A. Lawrence, and B. Baxter. A review and assessment of fare capping as a passenger incentive mechanism for Australia and New Zealand. *Australasian Transport Research Forum (ATRF), 37th*, 2015.
5. Chu, A., A. Lomone, and R. Chapleau. Evaluating the Impact of Fare Capping and Guaranteed Best Fare Policies. In *Transit Data Paris*, Paris, 2019.
6. City Of Chicago. 2020. *E-Scooter Pilot Evaluation* [Online]. City Of Chicago. Available: Https://Www.Chicago.Gov/Content/Dam/City/Depts/Cdot/Misc/Escooters/E-Scooter_Pilot_Evaluation_2.17.20.Pdf [Accessed Jul 14, 2020 2020].
7. Evans, J.E. (2004) TCRP Report 95: Traveler Response to Transportation System Changes, Chapter 9: Transit Scheduling and Frequency. *Transportation Cooperative Research Program, Report,* 95.
8. Halvorsen, Anne, Daniel Wood, Darian Jefferson, Timon Stasko, Jack Hui, and Alla Reddy. 2021. "Examination of New York City Transit's Bus and Subway Ridership Trends During the COVID-19 Pandemic." *Transportation Research Record*: 03611981211028860.
9. Hu, Songhua, and Peng Chen. 2021. "Who left riding transit? Examining socioeconomic disparities in the impact of COVID-19 on ridership." *Transportation Research Part D: Transport and Environment* 90: 102654.
10. Jenelius, Erik, and Matej Cebecauer. 2020. "Impacts of COVID-19 on public transport ridership in Sweden: Analysis of ticket validations, sales and passenger counts." *Transportation Research Interdisciplinary Perspectives* 8: 100242.
11. Kamargianni, M., W. Li, M. Matyas, and A. Schäfer. A Critical Review of New Mobility Services for Urban Transport. No. 14, 2016, pp. 3294–3303.
12. Lau, P. S. C. Developing a Contactless Bankcard Fare Engine for Transport for London. *Department of Civil and Environmental Engineering, Master of Science in Transportation*, Massachusetts Institute of Technology, Boston, MA, 2009.
13. Lu, M., Traut, E. & Guler, S. Spatiotemporal Analysis Of The Relationship Between Micromobility, Transit, And Traffic. Transportation Research Board 100th Annual Meeting, 2021 Washington D.C
14. Lyons, G., P. Hammond, and K. Mackay. The Importance of User Perspective in the Evolution of MaaS. *Transportation Research Part A: Policy and Practice*, Vol. 121, 2019, pp. 22–36. https://doi.org/10.1016/j.tra.2018.12.010.
15. McCollom, B.E., Pratt, R. (2004) TCRP Report 95: Traveler Response to Transportation System Changes, Chapter 12 Transit Pricing and Fares. *Transportation Research Board of the National Academies, Washington, DC*, pp.

16. Mobility Lab, Arlington County Commuter Services (Accs), 2019. Arlington County Shared Mobility Devices Pilot Evaluation Report.
17. Molina, Antonio, Narendra Malalgoda, Ali Rahim Taleqani, Jeremy Mattson, Kenechukwu Ezekwem, Taraneh Askarzadeh, And Jill Hough. 2021. *Surveys of Transit Riders and Agencies During The COVID-19 Pandemic.*
18. Orro, Alfonso, Margarita Novales, Ángel Monteagudo, José-Benito Pérez-López, and Miguel R Bugarín. 2020. "Impact on city bus transit services of the COVID–19 lockdown and return to the new normal: the case of A Coruña (Spain)." *Sustainability* 12 (17): 7206.
19. Pettine, A. *Transit Fare Capping: Balancing Revenue and Equity Impacts.* Transportation Research Board, Washington, D.C. https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=5013. Accessed May 31, 2021.
20. Pérez-Fernández, O., and J. C. García-Palomares. Parking Places to Moped-Style Scooter Sharing Services Using GIS Location-Allocation Models and GPS Data. *ISPRS International Journal of Geo-Information,* 2021. 10: 230.
21. Polydoropoulou, A., I. Pagoni, A. Tsirimpa, A. Roumboutsos, M. Kamargianni, and I. Tsouros. Prototype Business Models for Mobility-as-a-Service. *Transportation Research Part A: Policy and Practice*, Vol. 131, 2020, pp. 149–162. https://doi.org/10.1016/j.tra.2019.09.035.
22. Reck, D. J., D. A. Hensher, and C. Q. Ho. MaaS Bundle Design. *Transportation Research Part A: Policy and Practice*, Vol. 141, 2020, pp. 485–501. https://doi.org/10.1016/j.tra.2020.09.021.
23. Sandoval, R., C. Van Geffen, M. Wilbur, B. Hall, A. Dubey, W. Barbour, and D. B. Work. Data driven methods for effective micromobility parking. *Transportation Research Interdisciplinary Perspectives,* 2021. 10: 100368.
24. Sochor, J., M. Karlsson, and S. Sarasini. *A Topological Approach to Mobility as a Service: A Proposed Tool for Understanding Requirements and Effects, and for Aiding the Integration of Societal Goals*. 2017.
25. Taylor, B.D., Miller, D., Iseki, H., Fink, C. (2009) Nature and/or Nurture? Analyzing the Determinants of Transit Ridership across Us Urbanized Areas. *Transportation research part A: policy and practice,* 43, pp. 60-77.
26. Taylor, B., Fink, C., (2013) Explaining Transit Ridership: What Has the Evidence Shown? *Transportation Letters,* 5, pp. 15-26.
27. United Nations Economic Commission for Europe, and Inland Transport Committee. *Transport Trends and Economics 2018-2019: Mobility as a Service*. 2020.
28. Wang, Haoyun, and Robert B Noland. 2021. "Bikeshare and subway ridership changes during the COVID-19 pandemic in New York City." *Transport policy* 106: 262-270.
29. Watkins, K., Berrebi, S., Erhardt, G., Hoque, J., Goyal, V., Brakewood, C., Ziedan, A., Darling, W., Hemily, B., Kressner, J. (2021) *Tcrp 231: Recent Decline in Public Transportation Ridership: Analysis, Causes, Responses.* Transportation Research Board.
30. Wilbur, Michael, Afiya Ayman, Anna Ouyang, Vincent Poon, Riyan Kabir, Abhiram Vadali, Philip Pugliese, Daniel Freudberg, Aron Laszka, and Abhishek Dubey. 2020. "Impact of COVID-19 on public transit accessibility and ridership." *arXiv preprint arXiv:2008.02413*.
31. Xin, Mengwei, Amer Shalaby, Shumin Feng, and Hu Zhao. 2021. "Impacts of COVID-19 on urban rail transit ridership using the Synthetic Control Method." *Transport Policy* 111: 1-16.

32. Ziedan (2022). Emerging Trends in Bus Ridership in the United States. A Dissertation Presented for the Doctor of Philosophy Degree, The University of Tennessee, Knoxville.
33. Ziedan, Darling, Brakewood, Erhardt, and Watkins (2021). The impacts of shared e-scooters on bus ridership. Transportation Research Part A: Policy and Practice. Volume 153. pp. 20-34.

Appendix 1: Tennessee Transit Ridership Trends

This appendix presents additional results from the analysis of Tennessee ridership trends during COVID-19. Monthly ridership data were analyzed for all transit agencies in Tennessee. The National Transit Database (NTD)'s monthly module adjusted data release was used to analyze unlinked passenger trips (UPT), vehicle revenue miles (VRM), and vehicles operated in maximum service (VOMS). The data were analyzed for demand response, bus, and rail for all transit agencies in Tennessee that reported to the NTD from January 2018 to December 2021, and the detailed results can be found in Figure 6 through Figure 8 (for demand response), Figure 9 through Figure 11 (for bus), and Figure 12 through Figure 14 (for rail).

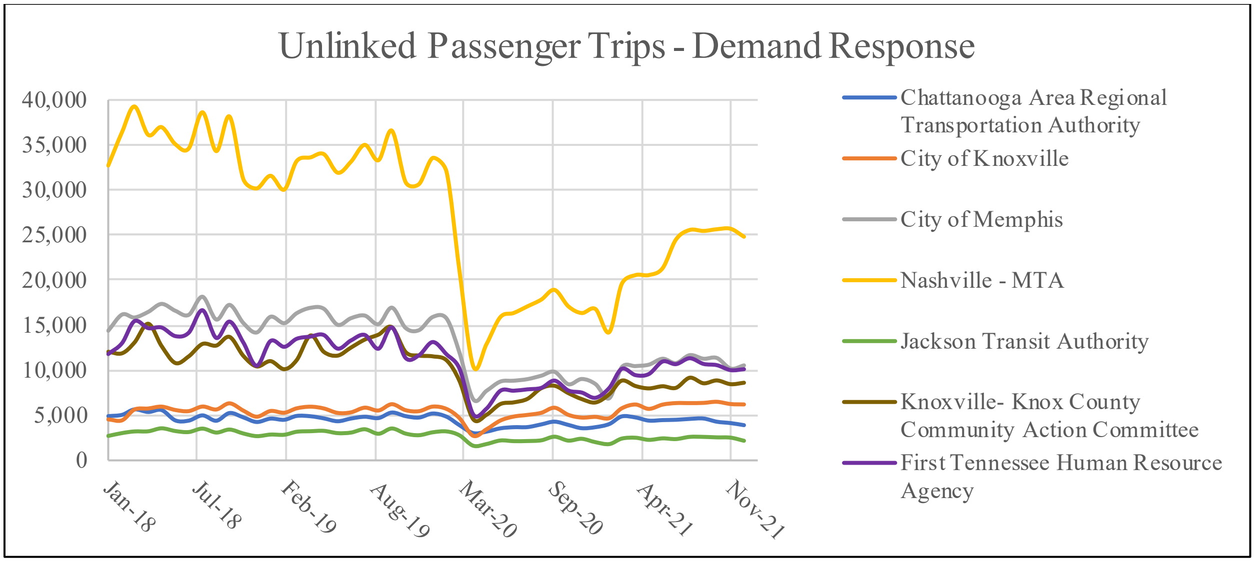

Figure 6: UPT for Demand Response Services in Tennessee

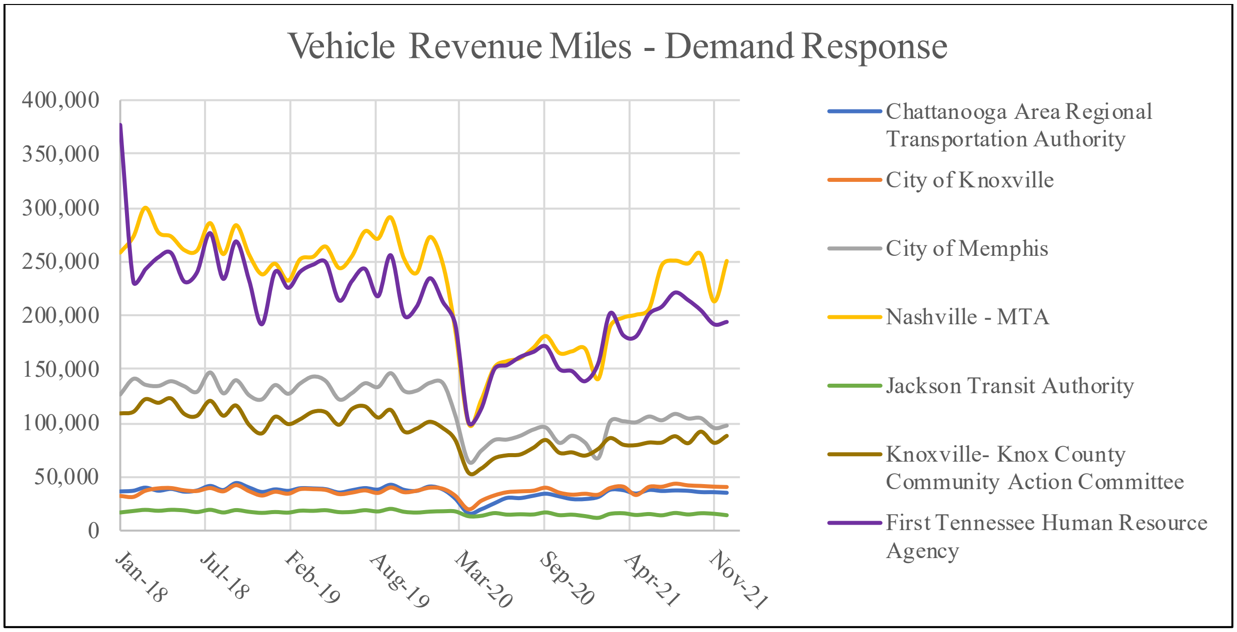

Figure 7: VRM for Demand Response Services in Tennessee

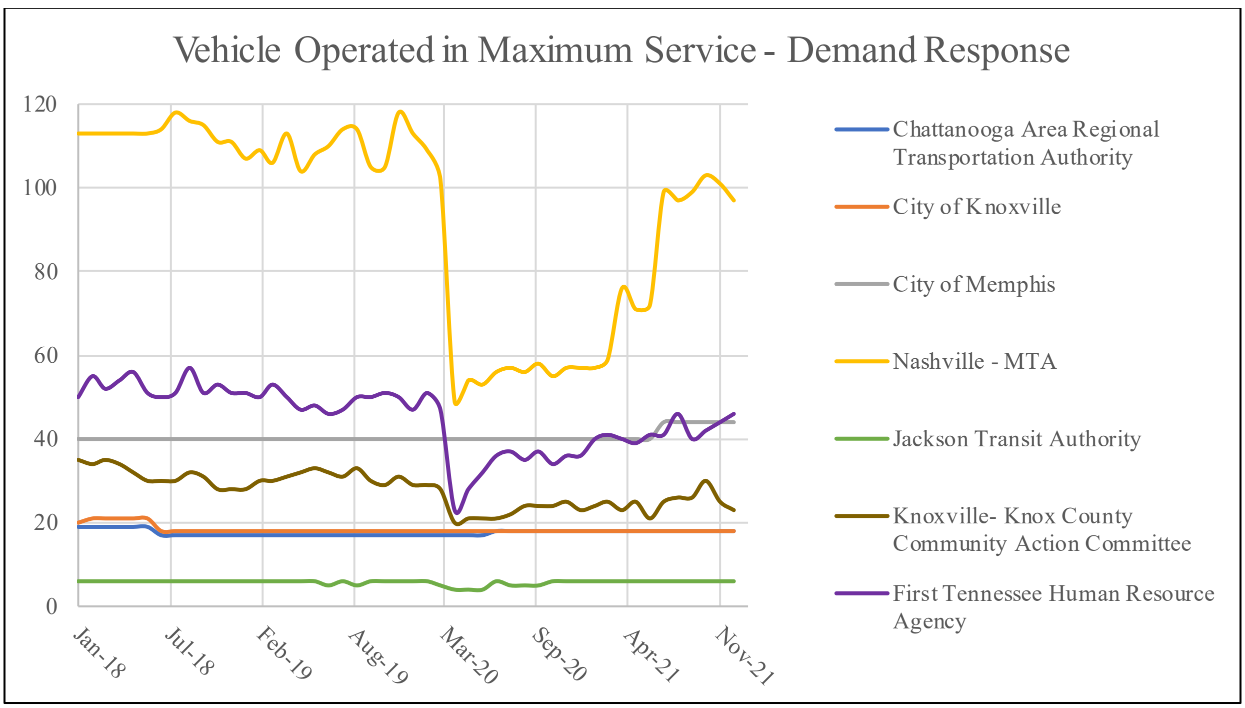

Figure 8: VOMS for Demand Response Services in Tennessee

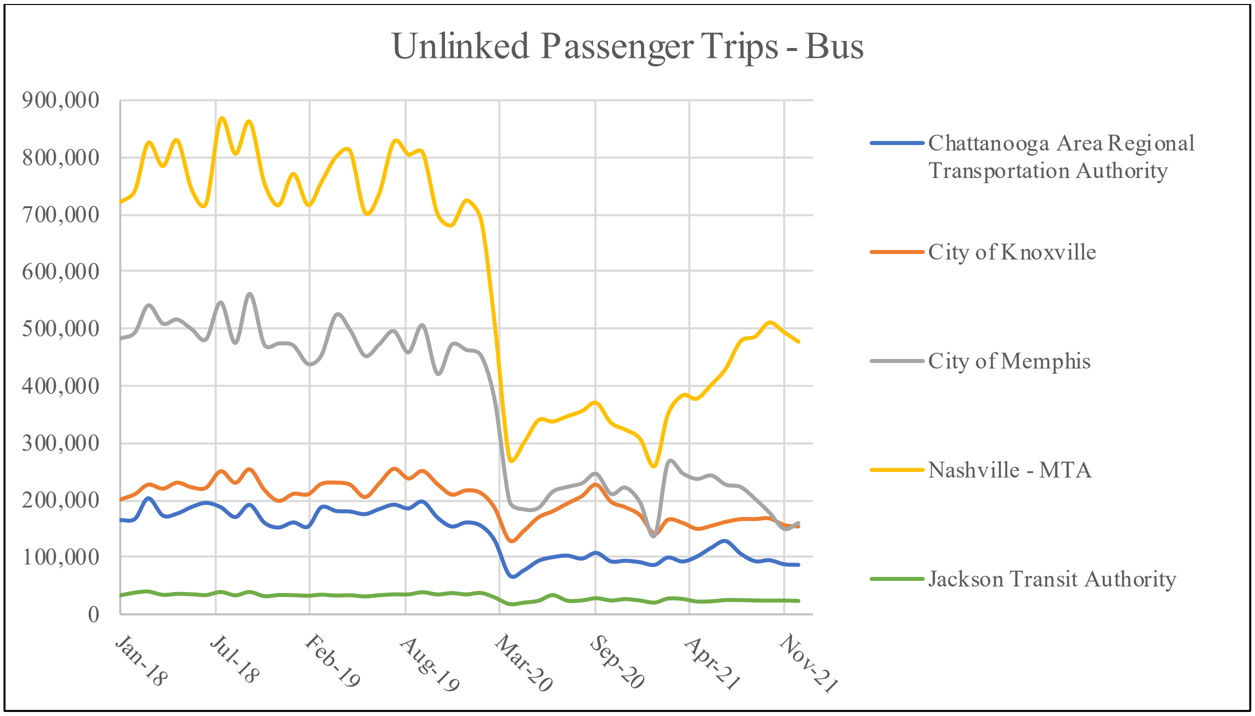

Figure 9: UPT for Bus Services in Tennessee

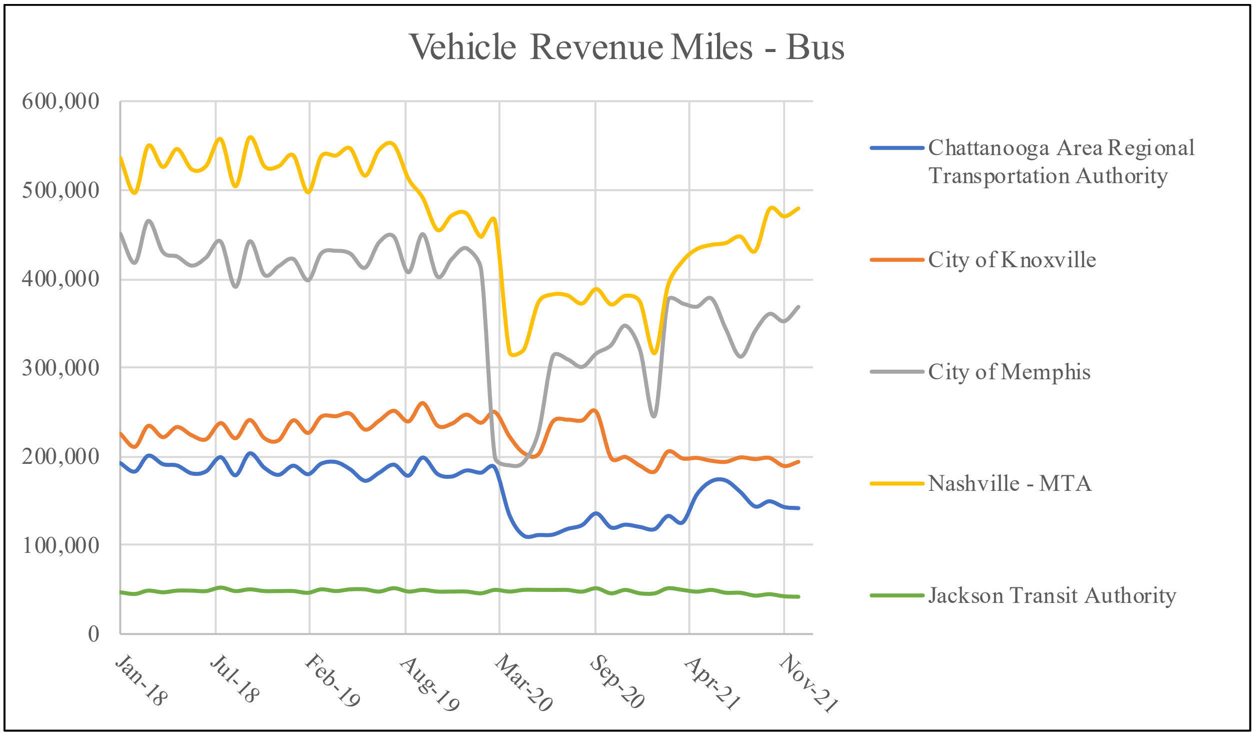

Figure 10: VRM for Bus Services in Tennessee

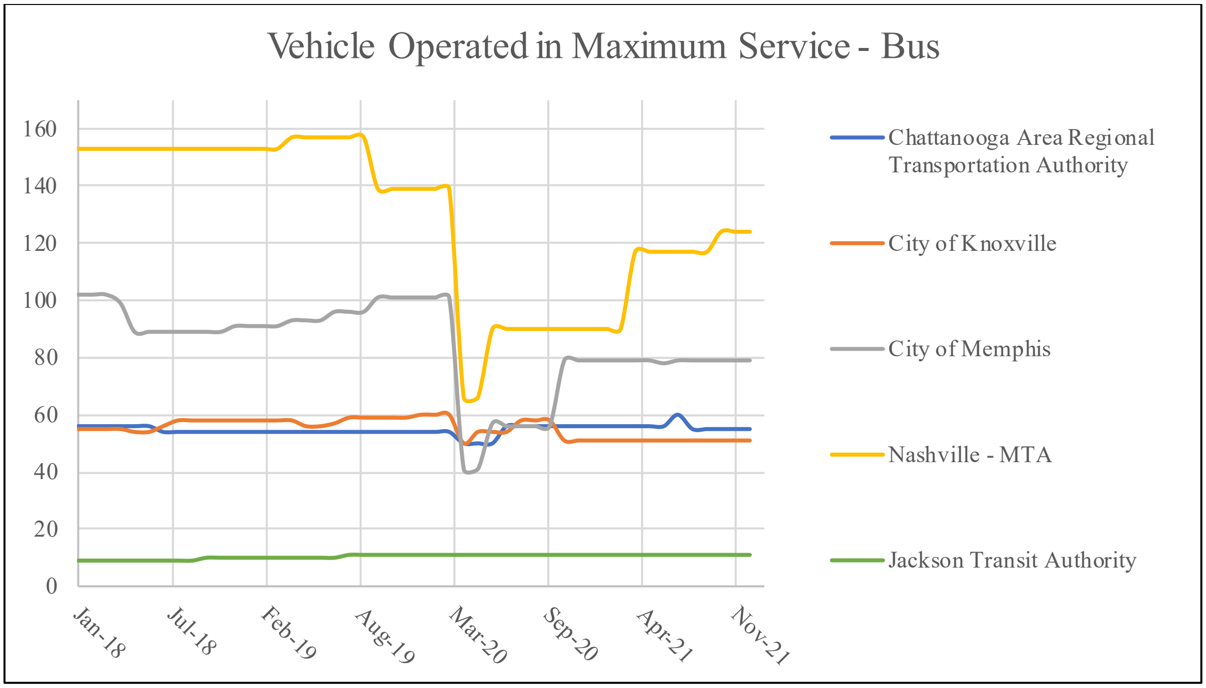

Figure 11: VOMS for Bus Services in Tennessee

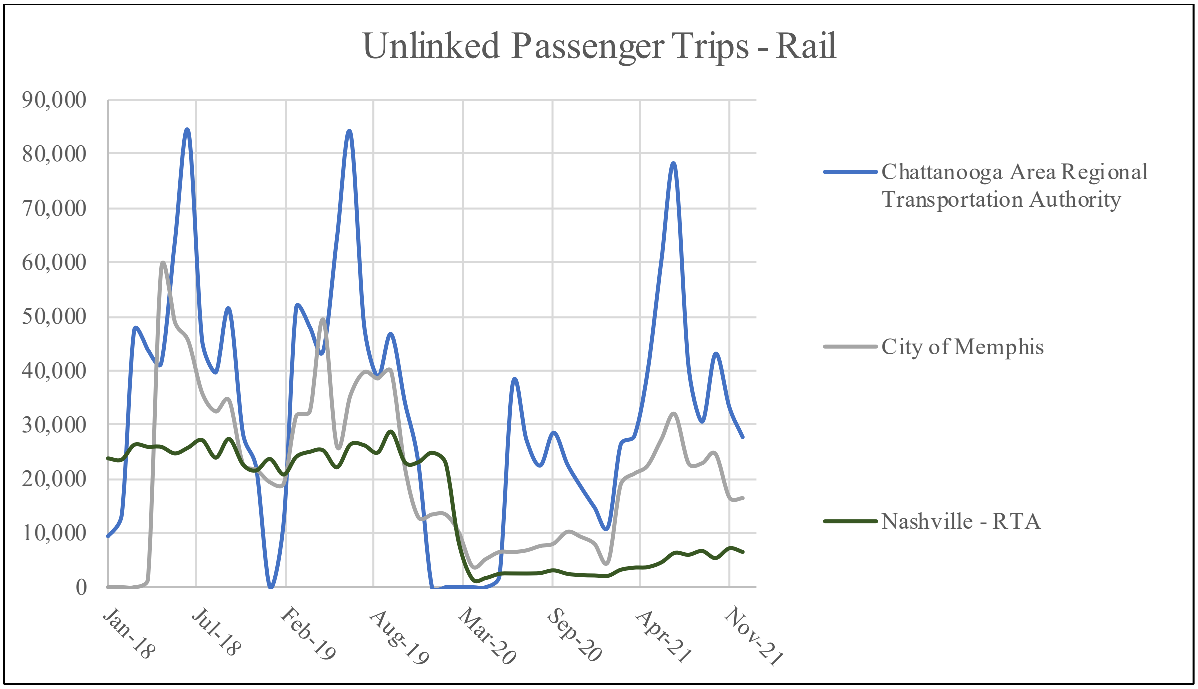

Figure 12: UPT for Rail Services in Tennessee

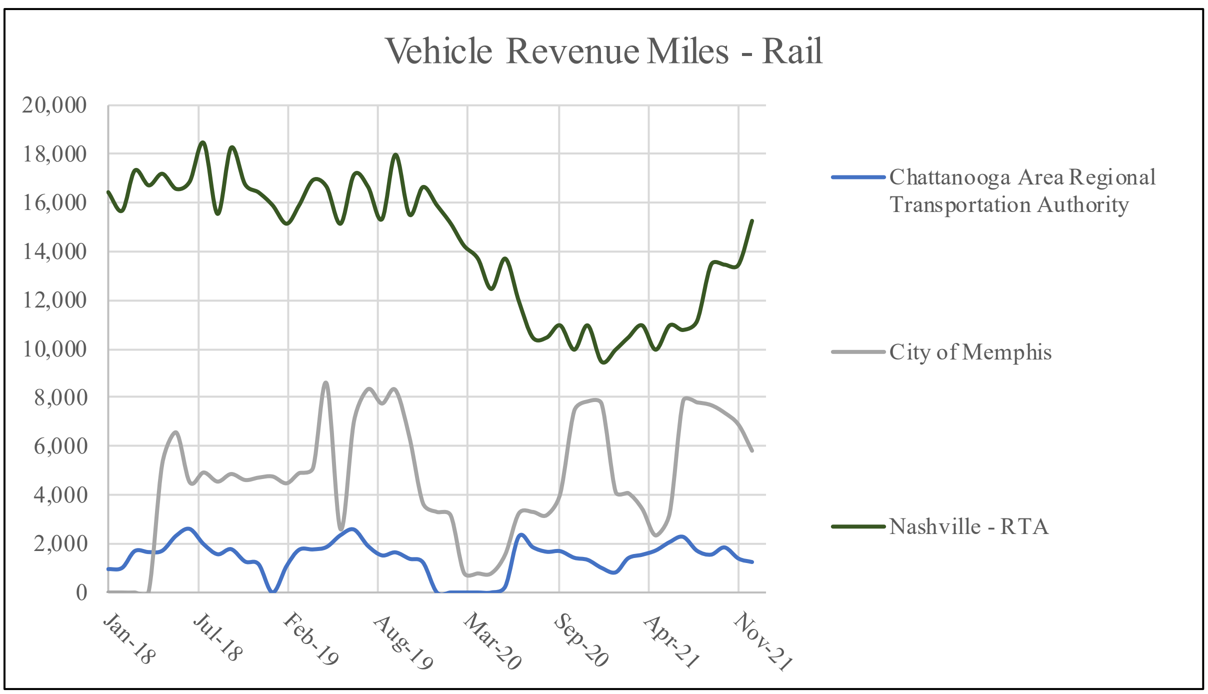

Figure 13: VRM for Rail Services in Tennessee

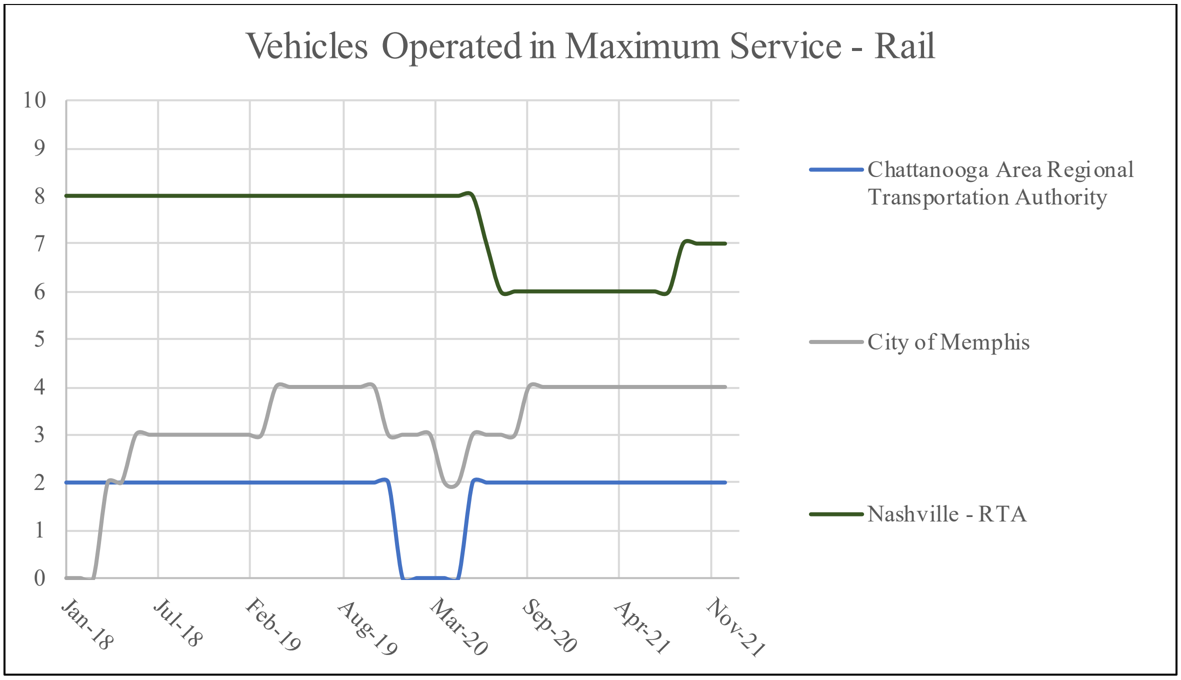

Figure 14: VOMS for Rail Services in Tennessee

Appendix 2: Proposed E-Scooter Corral Locations

Table 3: Proposed E-Scooter Corral Locations Near Transit in Nashville

Bus Stop Information from GTFS Data					Proposed Scooter Corral Information	
Bus Stop Id	Stop Code	Bus Stop Name	Stop Latitude	Stop Longitude	Rank	Proposed Capacity (based on the 85% percentile hour trips)
MXOMCCTR	MXOMCCTR	CONVENTION CENTER STATION OUTBOUND	36.159257	-86.776124	1	Large
MXIMCCTR	MXIMCCTR	CONVENTION CENTER STATION INBOUND	36.160899	-86.77444	2	Large
5AVGAYNN	5AVGAYNN	5TH AVE N & GAY ST NB	36.167822	-86.783106	3	Small
4AVCHUSN	4AVCHUSN	4TH AVE N & CHURCH ST SB	36.163796	-86.779079	4	Large
4AVBROSN	4AVBROSN	4TH AVE N & BROADWAY AVE SB	36.161063	-86.777296	5	Large
2AVCHUNN	2AVCHUNN	2ND AVE N & CHURCH ST NB	36.164545	-86.776836	6	Small
NXOPBODY	NXOPBODY	PEABODY STATION OUTBOUND	36.156137	-86.774063	7	Small
BRO3AWN	BRO3AWN	BROADWAY AVE & 3RD AVE WB	36.161616	-86.77595	8	Large
6AVDEASF	6AVDEASF	6TH AVE & DEADERICK ST SB	36.164652	-86.78286	9	Small
2AVBRONN	2AVBRONN	2ND AVE N & BROADWAY AVE NB	36.161821	-86.775075	10	Large
8ABROSN	8ABROSN	8TH AVE S & BROADWAY AVE SB	36.159047	-86.782292	11	Small
BRO2AEN	BRO2AEN	BROADWAY AVE & 2ND AVE S EB	36.16173	-86.775429	12	Large
2AVCOMNN	2AVCOMNN	2ND AVE N & COMMERCE ST NB	36.163214	-86.775995	13	Large
BRO2AWN	BRO2AWN	BROADWAY AVE & 2ND AVE N WB	36.161991	-86.775075	14	Large
6AVCHUSN	6AVCHUSN	6TH AVE N & CHURCH ST SB	36.16277	-86.781552	15	Small
CHA7AEN	CHA7AEN	CHARLOTTE AVE & 7TH AVE N EB	36.164714	-86.784416	16	Small
6AVCOMSN	6AVCOMSN	6TH AVE N & COMMERCE ST SB	36.161447	-86.780728	17	Small
4AVCOMSN	4AVCOMSN	4TH AVE N & COMMERCE ST SB	36.162511	-86.778241	18	Small
BRO9AWF	BRO9AWF	BROADWAY AVE & 9TH AVE S WB	36.158394	-86.783577	19	Small
4AARCADE	4AARCADE	4TH AVE & ARCADE SB	36.164616	-86.779573	20	Small