

# **Evolving Technologies Shaping Demand Responsive Transit**

Efon Mandong Epanty

Dissertation submitted to the Virginia Polytechnic Institute and State University faculty in partial fulfillment of the requirements for the degree of

Doctor of Philosophy  
In  
Planning, Governance, and Globalization

Thomas Sanchez, Chair  
Ralph Buehler  
Ralph Hall  
Christopher Zobel

November 29, 2023  
Arlington, Virginia

Keywords: paratransit, microtransit, on-demand transit, real-time dynamic dispatching, and scheduling technology.



## **Academic Abstract**

The transit industry is changing rapidly due to technology, which changes business models, ridership, travel patterns, and the transit workforce. As transit agencies introduce modern technology systems, research is needed on how these systems impact demand for paratransit and on-demand mobility services. This research addresses this topic by studying the impact of technology on demand-responsive transportation and urban mobility. Over the past two decades, this sector has been transformed by cloud computing, machine learning, artificial intelligence, ridesharing, and mobility-on-demand. This dissertation explores the adoption of innovative technology by transit agencies and service providers, focusing on implementing app-based dynamic technologies for dispatching and scheduling demand-responsive transportation modes such as microtransit services, on-demand transit, and paratransit.

Although studies on technological changes in other sectors have been conducted, public transit agencies need a more systematic approach to adopting new technology. Current literature on technology adoption in public transit focuses on the benefits and outcomes of technology adoption, with limited discussions of the challenges faced in adopting and implementing technologies. Comprehensive research on the emerging and evolving transit technological landscape is essential to bridge this gap. This research examines how transit agencies react to internal and external technological changes as their operational, tactical, and strategic operating conditions evolve. The aim is to enhance the current comprehension of the topic by providing a comprehensive overview of the technology adoption methodology and to offer practical planning and policy recommendations where possible.

A mixed-methods approach was applied to explore the research questions. Transit practitioners and managers in the Washington DC region were surveyed, and the analysis techniques employed included cross-tabulation and descriptive statistics. This dissertation focuses on gaining insight into adopting real-time dynamic dispatching and scheduling, on-demand transit, and microtransit technologies, including the opinions of transit practitioners and policymakers involved in facilitating technology adoption. Specifically, the study aims to 1) understand the impact of adopting emerging paratransit technologies; 2) investigate on-demand transit system performance outcomes under ridership, on-time performance, and operating costs, using a survey and expert interviews; and 3) investigate the use of a multicriteria decision-making approach to evaluate accessibility considerations in microtransit adoption planning and design strategies.

The results suggest that current technology adoption approaches in transit can significantly enhance decision-making and transit outcomes while addressing the equity and accessibility needs of the community and maintaining coverage and route frequency. The Socio-Technical-Systems (STS) approach was applied to help understand the adoption of new technology in demand response transit. This approach provides insights into technology, accessibility, decision-making, functionality, and interchangeability, enhancing our understanding of social complexity. Additionally, this research introduces a multi-level decision-making framework to measure service performance and provides insights into the impact of transportation technology on planning, policy, and decision-making processes.

## **Evolving Technologies Shaping Public Transit**

Efon Epanty

### **General Audience Abstract**

This research examines how transportation technology advancements affect mobility in the United States. It focuses on how transit agencies adapt to technological changes inside and outside the organization as their operating conditions evolve at operational, tactical, and strategic levels. This study aims to comprehensively understand this subject by offering a thorough overview of the technology adoption process and practical planning and policy recommendations where appropriate. The study delves into how real-time information coupled with new business models creates more accessible transit options and informed decisions. The research investigates on-demand transit, microtransit, and real-time dynamic dispatching and scheduling, which pose challenges regarding demand and costs. These technologies aim to maximize operational capacity and route frequencies and reduce vehicle travel time and mileage while considering the uncertainties of funding and travel behaviors that arise with technology adoption. The study examines three key technologies: 1) real-time dynamic dispatching and scheduling in paratransit, 2) performance outcomes of on-demand transit services in the Washington DC region, and 3) a multi-attribute decision-making approach in evaluating microtransit accessibility. The research reviews the technology adoption methods employed by transit agencies. It discusses the potential technology deployment of future projects in three domains: real-time dynamic dispatching and scheduling, on-demand transit, and microtransit accessibility.

## **Dedication**

I dedicate this dissertation to my late father, Venantius Ekangwo Epanty. I also dedicate this study to my mother, Anastasia Mandop Epanty. I could not have done this research without the unwavering support of my wife, Dilys Chebe, and the constant encouragement from my daughters, Jayne, Chelsea, Lauren, and Abigail.

# Acknowledgment

I am grateful for the valuable time and guidance provided by my committee members over the past three years. Thanks to Dr. Thomas Sanchez, my committee chair, for his outstanding advice. I am deeply thankful to Dr. Ralph Hall for his constant encouragement and guidance throughout my doctoral program. Additionally, I am indebted to Dr. Ralph Buehler and Dr. Christopher Zobel for their unwavering support and valuable advice on my dissertation research and professional development as a scholar. The expertise they provided has been immeasurable.

I am grateful to the entire UAP faculty and staff for their warm welcome and insightful guidance, which impacted me with the academic knowledge and skills to excel. Being a part of the VT SPIA community is truly an honor, and I am thankful for the opportunity to be part of the VT SPIA family. I will remember the friendships, growth, and learning with such a supportive group. Furthermore, I express my heartfelt appreciation to all the participants in my research study, including interviewees and survey respondents, and the reviewers who provided constructive feedback on my research.

Finally, I want to express my gratitude to my beloved wife. Her support throughout this long and arduous journey has been the anchor that kept me focused and determined to achieve my academic goals.

# Table of Contents

Academic Abstract .....	ii
General Audience Abstract .....	iv
Dedication .....	v
Acknowledgment .....	vi
Table of Contents .....	vii
LIST OF TABLES .....	ix
TABLE OF FIGURES .....	x
<b>1 Introduction.....</b>	<b>1</b>
1.1 Background .....	1
1.2 Motivation .....	7
1.3 Philosophical and Theoretical Foundations.....	8
1.4 The Technology Implementation Setting.....	8
1.5 Factors Influencing Technology Changes in Public Transit .....	9
1.6 Need for New Technology in Paratransit.....	14
1.7 Research Questions.....	17
1.8 Research Methodology .....	19
1.9 Limitations .....	20
1.10 References .....	21
<b>2 Real-Time Dynamic Dispatching and Scheduling in Paratransit: A Literature Review.....</b>	<b>26</b>
2.1 Introduction .....	26
2.2 Purpose.....	28
2.3 Background Literature .....	28
2.4 Research Questions.....	32
2.5 Methods.....	32
2.6 Literature Review .....	37
2.6.1 The State-of-the-Art Practices in Paratransit.....	37
2.6.2 The “Dial-A-Ride Problem” (DARP).....	44
2.6.3 Types of RT-DDS Technology.....	45
2.7 Discussion .....	51
2.7.1 What are the current models, practices, and approaches used for RT-DDS adoption in paratransit?.....	52
2.7.2 What types of RT-DDS operating systems are available? .....	53
2.7.3 What are the Benefits and Functionalities of RT-DDS System Adoption in Paratransit? .....	57
2.7.4 Summary of Challenges Facing Paratransit Today.....	61
2.8 Limitations .....	65
2.9 Conclusion.....	66
2.10 References .....	67
<b>3 On-Demand Transit (ODT): An Exploratory Case Study of Washington DC’s Efforts to Improve Service Outcomes .....</b>	<b>80</b>
3.1 Introduction .....	81
3.2 Background Literature .....	82
3.3 Research Questions.....	97
3.4 Research Methods.....	97
3.5 Results and Findings.....	103
3.5.1 DCNC Case Study .....	103
3.5.2 Survey Findings .....	113
3.5.3 Summary Findings from Interviews .....	117

3.5.4 Summary Findings from the DCNC Case Study .....	122
3.6 Conclusion.....	125
3.7 References .....	127
<b>4 A Multi-Attribute Decision-Making Approach to Measuring Microtransit Accessibility.....</b>	<b>134</b>
4.1 Introduction .....	135
4.2 Purpose and Objectives.....	138
4.3 Literature Review .....	139
4.4 Research Questions.....	151
4.5 Research Methods.....	152
4.5.1 The Three-Step MADM Approach.....	154
4.5.2 The MADM Case Study.....	157
4.6 Case Study Findings and Results.....	162
4.7 Conclusion.....	169
4.8 References .....	170
<b>5 Conclusion .....</b>	<b>176</b>
5.1 Main Findings and Contributions .....	177
5.2 Real-Time Dynamic Dispatching and Scheduling in Paratransit: A Literature Review .....	180
5.3 On-Demand Transit (ODT): An Exploratory Case Study of Washington DC’s Efforts to Improve Service Outcomes.....	183
5.4 Multi-Attribute Decision-Making Approach to Measuring Microtransit Accessibility.....	184
5.5 Main Findings and Summary .....	185
5.6 Limitations and Future Research .....	187
5.7 Future Work .....	188
5.8 References .....	189
<b>Appendices.....</b>	<b>190</b>
Appendix A: Survey Questions.....	190
Appendix B: Semi-Structured Interview Guide & Consent Forms .....	196

## LIST OF TABLES

Table 1. Exclusion and Inclusion Selection Criteria .....	35
Table 2. Selection Criteria for Category Formulation .....	36
Table 3. Five Components of the RT-DDS System .....	38
Table 4. Types of Real-time Dynamic Scheduling and Dispatching Technologies .....	46
Table 5 RT-DDS Investment and DRT/Paratransit Business Models .....	48
Table 6. Summary and Comparison of On-demand and Traditional Paratransit Systems.....	51
Table 7 MOD Business Models for Paratransit and On-Demand Transit .....	52
Table 8. RT-DDS Operating Systems .....	54
Table 9. RT-DDS Deployment and Implementation Schemes in Paratransit .....	56
Table 10 Summary of Key Terminology Associated with ODT.....	85
Table 11. Types of On-demand Transit (ODT) Models .....	86
Table 12 Proposed ODT Performance Measures Used .....	95
Table 13 Summary of DCNC Service Characteristics.....	105
Table 14 Microtransit Choice and Accessibility Goals and Priorities.....	147
Table 15 Interview Data Variables and Question Prompts.....	153
Table 16 Assessment Framework.....	154
Table 17 Microtransit Propensity Scoring System.....	155
Table 18 LOS Measures Based on Demand Response Service .....	156
Table 19 WAS Matrix .....	157
Table 20WAS Weighing Microtransit Propensity Scoring System .....	157
Table 21 Characteristics of Montgomery County, Ride On Flex Study Area and Ridership .....	158
Table 22Overview of PGC Link .....	161
Table 23. Spatial Coverage Variables and Attributes.....	163
Table 24. Level of Service Variables and Attributes.....	163
Table 25 Microtransit Accessibility Composite Matrix .....	166
Table 26 Research Gaps, Key Questions, and Findings and Contributions.....	177

# TABLE OF FIGURES

Figure 1- Identification and Screening of Studies.....	34
Figure 2 Timeline of Advancements Relating to Ride-Sharing Schemes & Technologies .....	40
Figure 3 A Typical ODT Service Delivery Model.....	88
Figure 4 DCNC Service Area Map for 2021 .....	104
Figure 5 Northeast Zone .....	106
Figure 6 Average Trip Duration.....	107
Figure 7 Average Wait Time .....	108
Figure 8 Average Daily Ridership.....	108
Figure 9 Ward 8 Zone.....	109
Figure 10 Average Trip Duration.....	111
Figure 11 Average Wait Time.....	111
Figure 12 Ridership Average Daily Passengers Served .....	112
Figure 13 Operating Costs .....	113
Figure 14 Distribution of Survey Responses and Completion .....	114
Figure 15 Survey Respondents by Work Location.....	114
Figure 16 Geographic Area of Transit Services.....	115
Figure 17 Agency Type or Category .....	115
Figure 18 Performance Measures Used for ODT Decision-Making.....	116
Figure 19 Opinion on ODT and Paratransit Cost Comparison .....	117
Figure 20 Summary of Key Themes from Interviews .....	119
Figure 21 Interview Responses to Questions About ODT Performance .....	121
Figure 22 Ride On Flex Rockville Zone.....	159
Figure 23 - Ride On Flex Glenmont Zone .....	160
Figure 24 PGC Link Fort Washington Zone.....	162
Figure 25: What do you think about microtransit accessibility?.....	164
Figure 26 What is being done to enhance microtransit accessibility (follow-up question) .....	165
Figure 27 Reliability (missed trips, delays, wait-time, and travel time).....	165
Figure 28 Coverage (easy access to key destinations).....	166

# 1 Introduction

Chapter one of this dissertation serves as the introduction and provides the general background and significance of the research topics. This chapter discusses the reasons behind the study and identifies the factors influencing technology adoption in transit while summarizing the research motivation. The chapter also provides an overview of recent changes that have impacted paratransit services across many U.S. cities. Section 1.1 presents an overview of the transit industry's current trends, opportunities, and challenges. Section 1.2 covers the general purpose and objectives of the research. A discussion of the philosophical and theoretical context of an evolving technology landscape in paratransit and public transit is provided in Section 1.3. Section 1.4 explains the rationale for the study and the technology implementation setting in paratransit. Section 1.5 outlines the factors influencing technological changes in paratransit, clarifying and framing the technology topics under investigation. Section 1.6 explores technology needs in paratransit to narrow the study and fill existing knowledge gaps while implementing new technologies in paratransit. Section 1.7 outlines the research questions and situates the key questions and research chapters. Section 1.8 provides an overview of the data collection methods and discusses the study's limitations. Section 1.9 outlines the research and summarizes the key insights and findings.

## 1.1 Background

Digital transportation technologies enabling on-demand services are transforming the transit landscape. There is a growing demand for app-based, flexible services. This is due to rapid technological advances, real-time, location-based data and smartphone applications availability, and the emergence of cloud-based computing and app-based transportation services (Conway et al., 2018; Alemi et al., 2018). The constantly evolving transportation industry has been impacted by new

businesses entering the market and the emergence of mobile apps and shared-use platforms. The combination of these technologies and business models has enabled transit providers to introduce a broad range of on-demand transit services to enhance paratransit efficiency and quality of service (Alemi et al., 2019; Kaufman et al., 2016). In 2016, the national expenditure on paratransit services was approximately \$5.2 billion, and the demand for such services is anticipated to increase, resulting in a continual rise in costs (Kaufman et al., 2016).

New transportation technologies and mobility options, such as on-demand transit and microtransit services, provide flexible, fast, frequent, and reliable choices to connect people to new opportunities. With the advancement of information and communication technology (ICT), riders expect more on-demand transit options and services. To address ridership, reduce operating costs, and cater to the growing need for more flexible mobility options, many transit agencies have piloted or implemented on-demand transit and microtransit services. These changes in paratransit services are expected to continue evolving with the integration of innovative technologies by 2030 as transit providers deploy new technologies to attract more users (Tuan, 2015; Hemily, 2004). Furthermore, transit agencies are exploring flexible service options to serve more people by adopting cost-effective and operationally scalable technologies compared to conventional solutions (Potts et al., 2010). These new technology systems are dynamic and offer flexible options that promise to address various mobility needs, including persons with disabilities and older adults. While transit patterns have shifted to changes in travel behaviors and patterns in the U.S., more recent changes in the past decade have been more pronounced and significant due to low transit ridership despite transit agencies' implementation of technological changes (Shaheen and Cohen (2018). At the same time, transit is facing more competition from Transport Network Companies (TNCs). The number of TNCs, mobility providers, and public agencies offering on-demand mobility services has increased in the past decade, as Volinski (2019) observed.

## Fixed Route, On-demand, and Demand Responsive Transit Systems

Transit agencies and providers serve riders through different transportation modes. This study used the following descriptions of transportation modes (Goldstein et al., 2016).

- **Fixed-route bus service:** Services provided on a repetitive, fixed schedule basis along a specific route with vehicles stopping to pick up and deliver passengers to specific locations; each fixed route trip serves the same origins and destinations, such as rail and bus (MB); unlike demand responsive (DR) and vanpool (VP) services.<sup>1</sup> This category includes bus rapid transit, commuter bus, and trolley bus (Goldstein et al., 2016).
- **Paratransit service** is defined as an accessible, origin-to-destination transportation service that operates in response to calls or requests from customers (Goldstein et al., 2016). It also refers to different shared mobility and last-mile options for public transit systems that operate unscheduled mobility services using small vehicles such as vans, sedans, and taxis.  
  
Comprehensive paratransit services (ADA paratransit) are required by the Americans with Disabilities Act (ADA).
- **Demand-response (dial-a-ride)** is an intermediate form of public transit with vehicles operating in response to passenger calls or requests. Small buses, vans, or taxis provide transportation services not on a fixed route or schedule. For example, transportation may be offered to individuals whose access may be limited or whose health condition prevents them from using the regular fixed-route bus service (Papanikolaou et al., 2017; Goldstein et al., 2016).

---

<sup>1</sup> See National Transit Database at <https://www.transit.dot.gov/ntd/national-transit-database-ntd-glossary>

Paratransit is a shared, demand-responsive transit (DRT) mode of public transit that has existed for some time, intending to provide equitable access to public transit. According to Papanikolaou et al. (2017), traditional fixed-route buses run on a predetermined schedule and route while accommodating many riders. In contrast, paratransit does not follow fixed routes, and the service is not designed around designated stops or schedules.

Paratransit is known for being a more adaptable form of transportation, using smaller vehicles to serve a smaller market share. *Paratransit* is a shared mode that provides flexible point-to-point service (including hand-to-hand, curb-to-curb, or door-to-door) designed to meet the needs of persons with disabilities and older adults. It is also affordable, convenient, and flexible (Ehebrecht et al., 2018). Brake et al. (2004) refer to paratransit as demand-responsive transportation that is operated using small buses, vans, and sedans and serves the tailored needs of users. Paratransit can be less expensive compared to private ride taxi services. However, it is more costly than train and bus fixed-route transit services.

Paratransit systems are adopting technologies and are becoming more “flexible” by offering same-day or on-demand TNCs. A key feature of on-demand transit services is its real-time functionality. Unlike fixed-route services on a predetermined schedule, on-demand transit operates on a dynamic scheduling and routing framework that allows a real-time trip request to be matched with an available vehicle/driver through an app-based mobile platform.

Implementing app-based on-demand mobility services using ICT allows for flexible door-to-door or point-to-point services on demand, making microtransit services more adaptable than traditional paratransit services. Potts et al. (2010) outline four distinct service elements that differentiate paratransit and other demand-responsive services from conventional fixed route design:

1. small, more flexible vehicles with no fixed routes or designated stops.

2. pre-defined service area with flexible scheduling.
3. door-to-door or point-to-point service; and
4. real-time functionality and advanced booking.

### **Paratransit Planning and Decision-Making**

Transportation services that cater to specific demands and responses, like paratransit, face unique challenges that require complex strategic, tactical, and operational decision-making. Paratransit differs significantly from traditional bus services, as highlighted by Papanikolaou et al. (2017). Although the literature has explored the various challenges associated with paratransit and demand-responsive transit implementation, such as dynamic dispatching and scheduling technology adoption, there is a lack of an integrated approach that links all these components. Studies on decision-making at different planning levels – i.e., strategic (transit route design), tactical (service frequency and timetable), and operational (vehicle scheduling and dispatching) levels – still need to be undertaken to address this knowledge gap (Papanikolaou et al., 2017).

Municipalities and public transit agencies face increasing demands to cater to diverse markets that may require unconventional and cost-effective solutions. Flexible on-demand transit services have shown immense potential in meeting the mobility needs of individuals across the country. These services can benefit and address the requirements of the Americans with Disabilities Act (ADA), especially in suburban, small urban, and rural areas where mobility markets have low or irregular demand. Transit agencies can alter their traditional fixed-route and paratransit transit services into flexible services. To determine whether and under what circumstances the introduction of new technologies and on-demand transit services is feasible, a comprehensive analysis of planning and operating flexible transportation services as part of an array of options is necessary (Potts et al., 2010).

## **An Evolving Paratransit Landscape**

Paratransit services are essential to the public transit ecosystem (Balog et al., 1997; Roos & Alschuler, 1975). Current trends show that paratransit business models, ridership, customer travel patterns, and transit agencies are evolving and transitioning quickly because of information and communication technology changes. Based on these changes, the United States Department of Transportation (USDOT) Intelligent Transportation Systems Joint Program Office identifies that new institutional models are needed to accelerate the adoption of technology and that exploratory research into emerging technology solutions across government, academia, and the private sector (U.S. Department of Transportation, 2021). Across the transit industry, there is a growing presence of digital technology, including intelligent transportation system applications, and it is necessary to understand the adoption of technology in the context of paratransit – with a focus on digital technology implementation and what this means as transit agencies introduce new technology systems. Broadly, this research explores the literature on real-time dynamic dispatching and scheduling systems, the performance of on-demand transit in the Washington DC region, and the impact of multi-criteria decision-making on microtransit accessibility.

Wilbur et al. (2023) state that many transit agencies already operate ridepooling services such as microtransit and paratransit. However, transit agencies are adapting to the changing urban mobility landscape due to the rise of new rideshare and shared mobility services (Wilbur et al., 2023). While not entirely new, in the past decade, TNCs such as Uber and Lyft and other emergent mobility providers like RideCo and Via have been providing flexible and convenient mobility solutions serving first/last mile access (Circella & Alemi, 2018; Hall et al., 2018; Westervelt et al., 2018). Although the concept of on-demand transit is still evolving, their presence is already shaping demand-response paratransit through mode substitution and filling gaps in transit service (Acheampong et al., 2020). For example, Clewlow and Mishra (2017) argued that these services

have disrupted traditional transportation providers, including public transit agencies. They highlighted opportunities for transit agencies to efficiently harness new technologies, data, and business models that can increase access to transit. However, the objectives for adopting and constraints for implementing these services vary between agencies (Wilbur et al., 2023). As communities shift their focus from relying solely on cars, which require substantial investments in road and parking infrastructure, to adopting new technology-driven demand-response mobility options such as on-demand transit and microtransit, it is crucial to consider the role of these new technologies and mobility options within the existing paratransit context.

## **1.2 Motivation**

My motivation for this dissertation focuses on rethinking the delivery and planning of paratransit services. This research investigates how actors respond to internal and contextual factors as their operating environment continuously changes at operational and strategic levels. The study focuses on understanding sociotechnical changes that affect transit, particularly the role of technology in paratransit systems. The research will help transit agencies plan and implement on-demand transit and microtransit more effectively, ensuring accessibility and equity considerations in service design. Additionally, the study will provide insight into how a logical planning framework and institutional capacities support the current implementation of on-demand technologies in paratransit. There is a growing interest in how adopting new technologies can improve the delivery of paratransit services, with a focus on enhancing the quality of service and reducing customer-facing impacts. Transit agencies face many challenges, including demand uncertainty, unreliable bus schedules, and unpredictable operational conditions such as traffic jams and sprawling cities, leading to wait times and travel delays for riders. Scholars have extensively explored these issues. According to Masoud and Jayakrishnan (2017), the ride-matching problem is vital to demand-responsive

transportation or a peer-to-peer ride-sharing system. Some of the most significant issues surrounding paratransit systems include increasing trip demand from an aging population, traffic issues, high costs of operating a large vehicle fleet, and the absence of modern cloud-based automated technologies.

### **1.3 Philosophical and Theoretical Foundations**

This dissertation explores the impact of technological advancements in information and communication on the transit industry in the United States over the last two decades. The study examines the implementation of technical changes in demand-responsive transportation and their effects on urban mobility. The research utilizes the Socio-Technical-Systems (STS) approach to information systems design, which examines the motivations behind public transit's adoption of new technological systems (Appelbaum, 1997). It adds to the existing literature for enhancing our understanding of social complexity by examining the interactions of technology, accessibility, decision-making, functionality, and interchangeability of these elements. This research also introduces a multi-level decision-making framework to measure service performance. It provides insights into the impact of transportation technology on planning, policy, and decision-making processes. This study does not include investigating the constructs that directly influence an organizational and individual's intention to use technology. Therefore, the Technology Acceptance (TAM) framework is not an underlying theoretical construct for this study.

### **1.4 The Technology Implementation Setting**

Technology is now a critical part of transit operations and cost-efficiency development, especially as paratransit demand continues to grow while funding resources stay the same or are diminishing. The transit industry's use of new technologies is essential to an evolving service

environment for organizations, their employees, and customers (Feigon & Murphy, 2016; Murphy C., 2016). When designed and implemented effectively, digital technologies and automation, including real-time data, computer-aided dispatching, and dynamic trip scheduling and optimization, have been shown to increase service efficiency and on-time performance in paratransit service operations (Rodman & High, 2018; Sather, 2018; Volinski, 2019a). However, as transit agencies are devoting substantial resources to purchasing and establishing technology governance systems to realize cost efficiencies and expand ridership, there appears to be a lack of published research in transportation technology implementation. More specifically, research needs to be conducted on dynamic scheduling technology for on-demand paratransit and microtransit, focusing on equity concerns and how technology adoption is rationalized in transit.

Therefore, systematic changes that involve redesigning the delivery and planning of paratransit services to optimize the use of technologies to provide customers with accessible, on-demand, and flexible mobility options are needed. Adopting new technologies will require successfully implementing emerging technologies, business practices, and policies. While the benefits of embracing new mobility technology in paratransit are clear, factors like demographic characteristics, socioeconomic status, travel costs, transport modes, quality of service, and land use patterns may affect these changes less noticeably (Mwale et al., 2022).

## **1.5 Factors Influencing Technology Changes in Public Transit**

There are many interconnected reasons for the emergence of new forms of transit. The following sub-sections explore these reasons, spanning social, economic, technological, and environmental aspects of public transit systems.

### ***Demand Uncertainty and Lack of Resources***

Paratransit systems face numerous challenges today, including scheduling problems, routing issues, and high operating costs. These challenges are due to shifts in travel behaviors, an aging population, and the requirement by the Americans with Disabilities Act (ADA) of 1990 that public transit agencies provide paratransit services to individuals with disabilities. Paratransit services are a safe and reliable transportation mode for disabled people. Despite low ridership due to COVID-19, current trends point to a demand recovery for paratransit ridership, with recent population and demographic data showing a significant latent demand for these services. The Bureau of Transportation Statistics reports that more than 25.5 million Americans have a travel-limiting disability, with about 3.6 million individuals unable to leave their homes due to disabilities and a lack of affordable, accessible transit (Rodman, 2022; Kaufman et al., 2016; Westervelt et al., 2018). Additionally, 45% of Americans need access to public transportation. As the population over 65 years increases to 20% of the nation's population by 2030, demand for paratransit services is expected to continue growing (Wolfe et al., 2020).<sup>2</sup>

Transit agencies face the challenge of meeting the increasing demand for paratransit services while controlling costs. To address this dilemma, transit agencies have invested in new technologies to shape public transit, including planning, policy, and delivery of paratransit services. However, successfully implementing these technologies and changing business models is crucial. Many transit agencies identify both system reliability and the need to address the issue of schedule adherence through new technologies as a challenge. Vehicle routing problems with real-time travel times are crucial for navigation in public transit networks and web-based travel information services (Okhrin & Richter, 2009).

---

<sup>2</sup> Travel Patterns of American Adults with Disabilities. Retrieved September 18, 2022, from [Travel Patterns of American Adults with Disabilities | Bureau of Transportation Statistics \(bts.gov\)](https://www.bts.gov/publications/research-report/2022/01/travel-patterns-of-american-adults-with-disabilities)

## ***Traffic Congestion***

Traffic congestion is a significant challenge when planning trips on public transit networks, and it is essential to find the most efficient transportation connections (Okhrin & Richter, 2009). Traffic congestion is a significant universal societal and public policy challenge in metropolitan areas worldwide, as people simultaneously attempt to get to work and school. In the Washington, D.C., metro area, 80% of commuters drive alone or carpool, while about 15% use public transit to travel to work (Begley et al., 2022). Furthermore, private vehicles are more comfortable, flexible, and convenient for completing multiple tasks on a single trip than most public transit options. Additionally, most jobs are concentrated in cities. At the same time, lower-income workers live farther from city centers, creating socioeconomic inequities in many communities because the cost of living in most cities is high (Remix (n.d.)). According to a study conducted by Haven Life in 2017, about 8.9 percent of workers had to travel one hour or more each way for their commute (Anderson, 2019). This makes setting up and operating public transportation challenging and is usually expensive due to coverage challenges (Remix (n.d.)). Instead of expanding infrastructure, which can be costly and damaging to the environment, Masoud and Jayakrishnan (2017) suggest that using existing transportation infrastructure more efficiently is an alternative way to address congestion. Therefore, technological solutions such as dynamic ride-sharing or real-time peer-to-peer ride-sharing systems are promising options for public transportation (Masoud & Jayakrishnan, 2017; Agatz et al., 2012; Shaheen & Chan, 2016). According to Cheng et al. (2020), Intelligent Transportation Systems (ITS) can optimize travel modes, navigation routes, and work trip schedules. For instance, optimization technologies can reduce single-occupant car use and improve transit capacity (Agatz et al., 2012). Pandey et al. (2019) argue that increasing vehicles could undermine ridesharing promises to alleviate city congestion. They present an optimization-based approach that

integrates Dial-A-Ride Problems (DARP) to compute the cost of assignments, vehicles, and requests.

### ***Rising Costs to Operate Transit***

Transit agencies need help with many problems, including traffic congestion, long commutes, and high operating costs. Among all transit agencies, the per-trip cost for ADA complementary paratransit is the highest (Partridge et al., 2020). These costs have increased because of increasing fuel prices, labor expenses, and maintenance costs. Antich (2019) notes that the cost of operating large fleets has contributed significantly to this problem. Paratransit ridership only accounts for 1-2% of a city's overall ridership but uses significant resources – estimated at least 9% of the total transit operating cost (Miah et al., 2020; Lolinski, 2019; Comfort, 2017). Additionally, the share of local and federal support for transit has been declining, except for emergency funding due to COVID-19. Greer (2020) reports that the federal government spent \$45.8 billion and \$17 billion on highways and mass transit, respectively, down from \$55.3 billion (about \$170 per person in the US) and up from \$15.2 billion in 2005. Given the high cost of operating a transit fleet and paratransit, transit agencies are eager to innovate and explore new business schemes to improve transportation.

### ***Finding Solutions in New and Emerging Technologies***

The transit industry is being transformed by new technologies that address its challenges. These advances allow public transit to offer a higher level of service that meets or exceeds the ADA requirements and extends paratransit beyond the ADA requirements. These new technologies can also help in effectively routing and matching vehicles and trips, reducing the operational costs of paratransit, and filling gaps in areas that lack fixed-route bus service because they are less populated and have dispersed trip patterns. Transit agencies are now implementing dynamic ride-share

technology systems to match riders with similar itineraries and schedules on short notice. This is a necessary component for successful optimization technology. In the coming years, fundamental changes will emerge in how bus and paratransit systems function, operate, and provide public services. Both public and private entities are increasingly testing new technologies such as real-time dynamic dispatching and scheduling, on-demand transit, and microtransit solutions for passenger transportation.

It is essential to understand the current industry trends and practices in using these technologies, identify factors that may increase or decrease adoption and acceptability, and evaluate the potential impact of these new technologies on public transit. Jariyasunan et al. (2011) note that mobile devices equipped with GPS and internet access are platforms with significant capabilities for merging static and real-time data, upon which transportation information can be shared and collected. Since 2012, when Uber started operating its commercial “ride-hailing” service that matches drivers with customers looking for rides in the United States, public transit has undergone many changes. During this time, several reports have identified high ridership demand and operating costs as critical challenges to the state of transit systems in the United States. New transit technologies offer opportunities for transit agencies to serve multiple areas with significantly different demand characteristics and improve mobility for historically disadvantaged populations.

### ***Technology Adoption in Paratransit***

The available literature indicates that transit agencies face limitations when it comes to adopting new technologies, including dynamic ridesharing, microtransit, and ridesourcing, which have garnered significant attention in recent years (Agatz et al., 2012; Pandey et al., 2019; Mourad et al., 2019). This is particularly relevant as transit agencies explore on-demand mobility services as an alternative mode of transportation for riders (Pandey et al., 2019). On-demand mobility, such as

microtransit systems, can supplement ADA complementary paratransit with relevant technology, utilizing cutaway vans from the ADA paratransit fleet to offer on-demand services to all users (Partridge et al., 2020; SUMC, 2017). Kaufman et al. (2016) suggest that implementing innovative solutions and new technology systems could enhance paratransit services. For instance, before the COVID-19 pandemic, New York City could have saved an estimated \$133 million annually through technological upgrades (Kaufman et al., 2016).

Transit agencies require new technologies to manage inherent growth and trip demand uncertainties. Transit leaders and policymakers are increasingly adopting transit technologies such as on-demand transit, real-time scheduling, dispatching systems, and microtransit to handle the challenges of demand growth. CapMetro serves as an excellent example of how transit providers can evolve to meet the changing expectations of riders while addressing scheduling gaps and reducing TRIP cancellations in its CapMetro Access ADA paratransit service. The agency has implemented an extensive automated technology and digitized platform for paratransit scheduling, dispatching, and automatic fare payment, allowing riders to receive real-time notifications about scheduled trips via voice, text, email, or a mobile app. Scholars have also examined emerging changes in travel behaviors and increasing inequality in many cities (Jariyasunant et al., 2011; Rossetti & Turitto, 1998; Adamski, 2014), proposing various technology schemes to counter these challenges (Newell & Potts, 1964). However, more clarity is essential to provide a local perspective on technology adoption in a constantly evolving mobility context and operational challenges.

## **1.6 Need for New Technology in Paratransit**

Information and communication technologies are expected to further enhance the provision of demand-responsive transit services (Alemi et al., 2019; Conway et al., 2018). For instance, the market share of for-hire vehicles doubled between 2009 and 2017, indicating significant growth in

this sector (Alemi et al., 2018). Local governments and transit agencies are facing challenges in adapting to the changing mobility landscape brought about by the emergence of new rideshare and shared mobility services. The implementation and adoption of technology in transit have been widely discussed in the literature, with various challenges identified. However, there are compelling reasons to consider such implementation. Firstly, public transit usage has undergone noticeable changes in terms of when and how it is used (Park & Chowdhury, 2022; Abdallah, 2023). Secondly, housing and demographic trends include an aging population requiring greater accessibility and renewed interest in demand-responsive and shared-ride public transit systems (Stanley & Hansen, 2023; Ho et al., 2018). Finally, the pandemic has accelerated these trends, with telecommuting becoming more widespread and traffic patterns changing daily (Downey et al., 2022; Echaniz et al., 2022). These changes bring multiple challenges, including adapting ridepooling formulations for real-world conditions and constraints. Another issue is the lack of modular and reusable software, making it challenging to implement and evaluate new ridepooling algorithms and approaches in real-world settings (Wilbur et al., 2023). Therefore, applying technological solutions is a critical strategy for managing growth in service demand and reducing operational costs (GAO, 2012; Higgins, 2000; Kane et al., 2016; Kaufman et al., 2016; Lave & Mathias, 2000). More research is needed on how technology has been implemented in transit (Becker et al., 2021; By, 2005; Murphy, 2016).

While some studies have identified challenges and barriers to implementing technology in transit, they have focused on specific technologies or systems, primarily for fixed route transit or traffic problems (Deng & Nelson, 2013; Shah et al., 2021; Rizos, 2010). A systematic mechanism for analysis is needed to fully understand the challenges of implementing technology in transit (Kaufman et al., 2016; Lave & Mathias, 2000). This research proposes a multi-pronged approach to technology adoption and integration to support the implementation of app-based and on-demand services in transit (Feigon & Murphy, 2016; Ma et al., 2019). It further aims to address this

knowledge gap by exploring emerging technologies and their implementation in a multimodal context, including:

- Exploring new transit technologies and their implementation challenges, including dynamic dispatching, on-demand transit, and microtransit.
- Examining how recent technologies in public transit can create a transportation system that offers an alternative to cars that is flexible, fast, reliable, and less expensive. Furthermore, this research aims to recognize and tackle obstacles and evaluate opportunities and barriers that transit organizations may encounter concerning technology-driven mobility services. It also proposes methods that transit can adopt, expand upon, and communicate with these novel modes, as established by Feigon and Murphy (2016).
- Analyzing research findings to show how the results can help improve services in a more targeted way. Given the growing interest in on-demand transit, this research explores the adoption of RT-DDS in paratransit.

This research will help provide a comprehensive view of technology adoption in paratransit, focusing on current practices and opportunities to boost paratransit reliability and cost-effectiveness. It will also help transit agencies and providers navigate technology challenges or opportunities and identify goals (e.g., addressing a particular service challenge, providing a new service, mapping out tech investments) based on examining current processes and circumstances around transit services (N-CATT, 2022).

## 1.7 Research Questions

This dissertation comprises three research articles presenting different yet interconnected research strands. All the articles address technology changes and adoption in paratransit, including real-time dynamic dispatching and scheduling, on-demand transit, and microtransit. Together, they offer a methodological approach to understanding the current technology adoption practices through a technology implementation lens. This research contributes to the academic literature by providing a detailed literature review with empirical insights into real-time dynamic dispatching and scheduling adoption in paratransit. It also identifies, categorizes, and integrates concepts related to microtransit accessibility, a growing research field. The overall structure of the dissertation is outlined below.

**Chapter One -Introduction:** This chapter introduces the rationale for the study, the factors that influence technology adoption, and the research motivation. It also provides an overview of the challenges faced by paratransit, including demand uncertainty, lack of resources, rising operating costs, and traffic congestion.

**Chapter Two (paper 1): Real-Time Dynamic Dispatching and Scheduling (RT-DDS) in Paratransit: A Literature Review.** This chapter presents a literature review of paratransit's real-time dispatching and scheduling technologies. The review summarizes previous studies on developing and implementing real-time dynamic dispatching and scheduling, also known as dynamic routing technology systems. The chapter analyzes literature from a technology adoption and implementation perspective. It also discusses routing problems in paratransit. The chapter addresses the following research questions:

1. What are the current models, practices, and approaches used for RT-DDS adoption in paratransit?

2. What types of RT-DDS operating systems are available?
3. What are the benefits and functionalities of RT-DDS system adoption in paratransit?

**Chapter Three (paper 2): On-Demand Transit (ODT): An Exploratory Case Study of Washington DC’s Efforts to Improve Service Outcomes.** This chapter provides a case analysis of three on-demand transit systems in the Washington DC region – DC Neighborhood Connect, Ride On Flex, and PGC Link. It explores the scope of on-demand transit implementation and associated performance outcomes based on operational and survey data. Interviews with transit managers in the region supplement the data. The chapter addresses the following research questions:

1. How does ODT improve transit outcomes?
2. What are the ODT service performance outcomes regarding ridership, on-time performance, and operating costs?
3. What are the technological features of ODT services, and how do they impact the performance outcomes of ODTs?
4. What are the causal linkages between ODT performance and paratransit?

**Chapter Four (paper 3): A Multi-Attribute Decision-Making Approach to Measuring Microtransit Accessibility.** This chapter examines microtransit accessibility using a multi-criteria decision-making approach. The chapter addresses the following research questions:

1. Why do agencies or operators want to implement microtransit?
2. How do accessibility factors impact decision-making in adopting microtransit?
3. How do practitioners think about microtransit?
4. To what extent does an organization use multi-attribute decision-making techniques to support decisions on microtransit adoption to increase transit accessibility, and how do these relationships impact microtransit accessibility?

**Chapter Five – Conclusion:** Chapter Five concludes the dissertation by summarizing the findings from the three papers. The implications of this research for policymakers are discussed, and future research opportunities are identified.

## 1.8 Research Methodology

The research problem of adopting on-demand technologies presents complex operations, planning, and policy issues (Conway et al., 2018; Alemi et al., 2018). The research process starts with exploratory research to determine the best ways to apply quantitative analysis when addressing various questions, collecting data, and providing different kinds of answers and analyses to answer research questions (Kennedy et al., 2013). Municipalities and transit agencies are implementing pilot programs to assess demand-responsive technologies and policies in selected service zones or neighborhoods. They are adjusting service design and needs before a systemwide implementation. I have based the research questions and methods on such settings to enhance planning and policy exploration. To address the research questions in this dissertation, I have employed a mixed-method approach that strategically integrates inductive and deductive thinking.

According to Muskat et al. (2012), mixed methods research in social sciences involves mixes or combinations of quantitative and qualitative research techniques, methods, approaches, and concepts. This approach has proven valuable for studying transportation in relation to agency, structure, and social practices (Creswell et al., 2004; Kennedy et al., 2013; Tiznado-Aitken et al., 2020). This approach is best suited to explore complex planning and policy topics, allowing for examining technological changes in paratransit and exploring business model policy scenarios in paratransit. This dissertation utilizes data from an online survey, expert interviews with public and transit officials, and literature reviews to address various research questions (Wasti et al., 2022). A combined approach increases our understanding of the broader applicability of small-sample qualitative findings (Creswell et al., 2011).

- Chapter 2 (paper 1) of this dissertation comprehensively reviews real-time dynamic dispatching and scheduling technologies. The review includes academic research and grey

literature to help understand the background research questions (Chen, 2017) and set the stage for the research questions for Chapters 3 and 4.

- I conducted a case study in Chapter 3 (paper 2) to examine the On-Demand Transit system in Washington, DC. A case study is a research method that involves an in-depth examination of a particular phenomenon, collecting and analyzing specific data to gain a thorough understanding (Starman, 2013). I have used a combination of survey and expert interview data to comprehensively understand the context surrounding the increased use of technology in demand-responsive transportation. I have explored the complexity of delivering on-demand transit services and integrating mobile transit technologies into the transit ecosystem by adopting a case study approach (O'Brien et al., 2014; Tight, 2017). This approach allows for understanding the impacts of current technology adoption practices and emerging mobility business models on the transportation system. The benefits of this approach include effectively utilizing the strengths of each type of data, leading to a more comprehensive understanding of the challenges related to technology adoption and the potential implications.
- Chapter 4 (Paper 3) uses a case study to investigate the accessibility of microtransit within a multi-attribute decision-making context. Survey and interview data were analyzed to determine if and how accessibility factors were considered in the planning and designing of the Ride On Flex and PGC Link microtransit systems in Montgomery and Prince George's Counties in Maryland. A case approach was used to examine this complex phenomenon comprehensively.

## **1.9 Limitations**

There are some limitations that the study encountered, including the ever-changing landscape of technology, variations between urban and non-urban areas, and the inability to generalize from a

single case study. There are ambiguities regarding a case study approach and in identifying research subjects for case studies (Starman, 2013). The COVID-19 pandemic significantly impacted the current and future transportation outlook, affecting the study's findings due to challenges in data collection. The study faced many non-responses from practitioners who could not be reached, and those interviewed provided limited information on the costs and performance of their transit services. The data collection targeted transit practitioners, including executives, managers, and planners. Interestingly, discussions with transit practitioners often revealed differing viewpoints, which may have influenced the analysis from the original conditions. However, no sensitivity analysis was done to assess any change in the interview and survey results. Future studies could investigate the need for a standard method for evaluating operational costs resulting from RT-DDS adoption compared to traditional paratransit. Improving current practices for adopting and implementing RT-DDS technologies can be explored further.

## 1.10 References

- Abdallah, T. (2023). Sustainable mass transit: Challenges and opportunities in urban public transportation.
- Acheampong, R. A., Siiba, A., Okyere, D. K., & Tuffour, J. P. (2020). Mobility-on-demand: An empirical study of internet-based ride-hailing adoption factors, travel characteristics, and mode substitution effects. *Transportation Research Part C: Emerging Technologies*, p. 115, 102638.
- Agatz, N., Erera, A., Savelsbergh, M., & Wang, X. (2012). Optimization for dynamic ride-sharing: A review. *European Journal of Operational Research*, 223(2), 295-303.
- Alemi, F., Circella, G., Handy, S., & Mokhtarian, P. (2018). What influences travelers to use Uber? Exploring the factors affecting the adoption of on-demand ride services in California. *Travel Behaviour and Society*, 13, 88-104.
- Alemi, F., Circella, G., Mokhtarian, P., & Handy, S. (2019). What drives the use of ride-hailing in California? Ordered probit models of the usage frequency of Uber and Lyft. *Transportation Research Part C: Emerging Technologies*, 102, 233-248.
- American Public Transportation Association (n.d.). *APTA Ridership Trends*.  
<https://www.Apta.com/Research-Technical-Resources/>. Retrieved October 4, 2023, from  
<https://www.apta.com/research-technical-resources/transit-statistics/ridership-report/>

- American Public Transportation Association. Public Transportation Facts. Available online: <https://www.apta.com/news-publications/public-transportation-facts/> (accessed on December 2, 2021)
- Anderson, T. (2019, January 15). *Cities with the best and worst commutes*. <https://Havenlife.com/Blog>. Retrieved August 15, 2022, from <https://havenlife.com/blog/longest-shortest-commutes-in-america/>
- Antich, M. (2019, December 30). *Fleets Concerned About Rising Operating Costs*. <https://www.Automotive-Fleet.com/>. Retrieved August 15, 2022, from <https://www.automotive-fleet.com/347656/fleets-concerned-about-rising-operating-costs>
- Appelbaum, S.H. (1997). "Socio-technical systems theory: an intervention strategy for organizational development," *Management Decision*, Vol. 35 No. 6, pp. 452-463. <https://doi.org/10.1108/00251749710173823>
- Badia, H., Estrada, M., & Robusté, F. (2014). Competitive transit network design in cities with radial street patterns. *Transportation Research Part B: Methodological*, 59, 161-181.
- Balog, J. N., Morrison, J. B., & Hood, M. M. (1997). Integration of paratransit and transit services: Importance of vehicle transfer requirements to consumers. *Transportation Research Record*, 1571(1), 97-105
- Begley, J., Brooks, L., McCabe, B. J., Schuetz, J., & Veuger, S. (2022). Greater Washington commuters continue to choose gridlock.
- Bostrom, R. P., & Heinen, J. S. (1977). MIS problems and failures: a socio-technical perspective, part II: the application of socio-technical theory. *MIS Quarterly*, 11-28
- Chen, C. (2017). Science mapping: a systematic review of the literature. *Journal of Data and Information Science*, 2(2), 1–40.
- Cheng, Z., Pang, M. S., & Pavlou, P. A. (2020). Mitigating traffic congestion: The role of intelligent transportation systems. *Information Systems Research*, 31(3), 653-674.
- Conway, M. W., Salon, D., & King, D. A. (2018). Trends in taxi use and the advent of ride-hailing, 1995–2017: Evidence from the US National Household Travel Survey. *Urban Science*, 2(3), 79.
- Creswell, J. W., Klassen, A. C., Plano Clark, V. L., & Smith, K. C. (2011). Best practices for mixed methods research in the health sciences. *Bethesda (Maryland): National Institutes of Health*, 2013, 541-545.
- Downs, A. (2004). *Traffic: Why it is getting worse, what government can do* (No. Policy Brief# 128). Washington, DC: Brookings Institution.
- Ehebrecht, D., Heinrichs, D., & Lenz, B. (2018). Motorcycle-taxis in sub-Saharan Africa: Current knowledge, implications for the debate on “informal” transport and research needs. *Journal of transport geography*, 69, 242-256.
- Feigon, S., & Murphy, C. (2016). *Shared mobility and the transformation of public transit* (No. Project J-11, Task 21).

- Greer, R. A. (2020). A review of public water infrastructure financing in the United States. *Wiley Interdisciplinary Reviews: Water*, 7(5), e1472.
- Hemily, B. (2004). Trends affecting public transit's effectiveness: A review and proposed actions
- Jariyasunant, J., Work, D. B., Kerkez, B., Sengupta, R., Glaser, S., & Bayen, A. (2011). Mobile transit trip planning with real-time data.
- Kaufman, Sarah M., Ashley Smith, Jenny O'Connell, and David Marulli. "Intelligent paratransit." (2016).
- Kennedy, E., Krahn, H., & Krogman, N. T. (2013). Taking social practice theories on the road: A mixed-methods case study of sustainable transportation. *Innovations in Sustainable Consumption*, 252-276.
- Lave, R., & Mathias, R. (2000). State of the Art of Paratransit. *Transportation in the New Millennium*, 478, 1-7.
- Ma, T. Y., Rasulkhani, S., Chow, J. Y., & Klein, S. (2019). A dynamic ridesharing dispatch and idle vehicle repositioning strategy with integrated transit transfers. *Transportation Research Part E: Logistics and Transportation Review*, 128, 417-442.
- Machek, E. C., & Peirce, S. (2021). Survey Research for Automated Shuttle Pilots: Issues and Challenges.
- Masoud, N., & Jayakrishnan, R. (2017). A real-time algorithm to solve the peer-to-peer ride-matching problem in a flexible ridesharing system. *Transportation Research Part B: Methodological*, pp. 106, 218–236.
- Mwale, M., Luke, R., & Pisa, N. (2022). Factors that affect travel behaviour in developing cities: A methodological review. *Transportation Research Interdisciplinary Perspectives*, 16, 100683.
- Muskat, M., Blackman, D. A., & Muskat, B. (2012). Mixed methods: Combining expert interviews, cross-impact analysis, and scenario development. *The Electronic Journal of Business Research Methods*, 10(1), 09-21.
- Ndibatya, I., & Booyesen, M. J. (2021). Characterizing the movement patterns of minibus taxis in Kampala's paratransit system. *Journal of Transport Geography*, 92, 103001
- O'Brien, B. C., Harris, I. B., Beckman, T. J., Reed, D. A., & Cook, D. A. (2014). Standards for reporting qualitative research: a synthesis of recommendations. *Academic Medicine*, 89(9), 1245–1251.
- Okhrin, I., & Richter, K. (2009). Vehicle routing problem with real-time travel times. *International journal of vehicle information and communication systems*, 2(1-2), 59-77.
- Pandey, V., Monteil, J., Gambella, C., & Simonetto, A. (2019). On the needs for MaaS platforms to handle competition in ridesharing mobility. *Transportation Research Part C: Emerging Technologies*, 108, 269-288.
- Papanikolaou, A., Basbas, S., Mintsis, G., & Taxiltaris, C. (2017). A methodological framework for assessing the success of Demand Responsive Transport (DRT) services. *Transportation Research Procedia*, 24, 393-400.

- Partridge, E., Murphy, C., Faust, R., Karner, K., Sethi, S., & Kaufman, M. (2020). *Mobility on Demand (MOD) Business Models Synthesis Report* (No. FHWA-JPO-20-798). United States. Department of Transportation. Federal Highway Administration
- Potts, J. F., Marshall, M. A., Crockett, E. C., & Washington, J. (2010). A guide for planning and operating flexible public transportation services. *TCRP Report*, p. 140.
- Remix (n.d.). *5 Transportation Issues And Challenges Facing US Cities And Their Solutions*. <https://www.Remix.com/Blog/>. Retrieved October 4, 2023, from <https://www.remix.com/blog/5-transportation-challenges-facing-us-cities>
- Rizos, A. C. (2010). *Implementation of advanced transit traveler information systems in the United States and Canada: practice and prospects* (Doctoral dissertation, Massachusetts Institute of Technology).
- Rodman, W. (2022). *ADA Paratransit and Other Demand-Responsive Transportation Services in Small to Midsized Transit Agencies* (No. TCRP Project J-07, Topic SG-19)
- Round, A., & Cervero, R. (1996). Future ride: Adapting new technologies to paratransit in the United States.
- Schweiger, C. L. (1996, October). Deployment of technology for paratransit: Examples of innovation. In *Vehicle Navigation and Information Systems Conference, 1996* (pp. 197-204). IEEE.
- Shah, K. J., Pan, S. Y., Lee, I., Kim, H., You, Z., Zheng, J. M., & Chiang, P. C. (2021). Green transportation for sustainability: Review of current barriers, strategies, and innovative technologies. *Journal of Cleaner Production*, 326, 129392.
- Shaheen, S., & Chan, N. (2016). Mobility and the sharing economy: Potential to facilitate the first-and last-mile public transit connections. *Built Environment*, 42(4), 573–588.
- Shaheen, S., & Cohen, A. (2018). Is it time for a public transit renaissance? *Journal of Public Transportation*, 21(1), 67–81.
- Starman, A. B. (2013). The case study is a type of qualitative research. *Journal of Contemporary Educational Studies/Sodobna Pedagogika*, 64(1).
- Talley, W. K., & Anderson, E. E. (1986). An urban transit firm providing transit, paratransit, and contracted-out services: a cost analysis. *Journal of Transport Economics and Policy*, pp. pp. 353-368
- The National Center for Applied Transit Technology (2022, June 6). *Identifying Fare Payment System Needs*. <https://N-Catt.org/>. Retrieved August 15, 2022, from <https://n-catt.org/procurement/identifying-fare-payment-system-needs/>
- Tight, M. (2017). *Understanding case study research: Small-scale research with meaning*. Sage.
- Tiznado-Aitken, I., Lucas, K., Muñoz, J. C., & Hurtubia, R. (2020). Understanding accessibility through public transport users' experiences: A mixed methods approach. *Journal of Transport Geography*, 88, 102857.
- Tuan, V. A. (2015). Mode choice behavior and modal shift to public transport in developing countries-the case of Hanoi city. *Journal of the Eastern Asia Society for Transportation Studies*, pp. 11, 473–487.

- U.S. Government Accountability Office (2017, May 15). *Technology in Transit*. Retrieved December 9, 2023, from <https://www.gao.gov/blog/2017/05/15/technology-in-transit>
- Volinski, J. (2019). Microtransit or general public demand–response transit services: state of the practice (No. Project J-7, Topic SB-30).
- Wasti, S. P., Simkhada, P., van Teijlingen, E. R., Sathian, B., & Banerjee, I. (2022). The growing importance of mixed-methods research in health. *Nepal Journal of Epidemiology*, *12*(1), 1175.
- Westervelt, M., Huang, E., Schank, J., Borgman, N., Fuhrer, T., Peppard, C., & Narula-Woods, R. (2018). UpRouted: Exploring Microtransit in the United States
- Wilbur, M., Coursey, M., Koirala, P., Al-Quran, Z., Pugliese, P., & Dubey, A. (2023, May). Mobility-On-Demand Transportation: A System for Microtransit and Paratransit Operations. In *Proceedings of the ACM/IEEE 14th International Conference on Cyber-Physical Systems (with CPS-IoT Week 2023)* (pp. 260–261).
- Wolfe, M. K., McDonald, N. C., & Holmes, G. M. (2020). Transportation barriers to health care in the United States: findings from the national health interview survey, 1997–2017. *American Journal of Public Health*, *110*(6), 815-822.

## **2 Real-Time Dynamic Dispatching and Scheduling in Paratransit: A Literature Review**

The chapter explores the interrelation of new technology systems and business changes in paratransit. It provides a literature review of real-time dynamic dispatching and scheduling technology systems, focusing on paratransit. The review identifies a gap that needs to be addressed through more scholarship on RT-DDS concerning technology implementation. Finally, the study highlights previous research studies that have found complementary associations between ridesharing and public transit use and the factors that influence technology adoption by transit agencies in paratransit.

### **Abstract**

US transit agencies are adopting on-demand technology to replace old paratransit scheduling methods. This technology uses real-time data to optimize scheduling and routing, resulting in shorter wait and ride times, improved efficiency, and reduced costs. However, implementation can be challenging. A systematic literature review was conducted to analyze seventy-six (76) studies from 2010 to 2022 and understand the current state of Real-time Dynamic Dispatching and Scheduling (RT-DDS) technology in paratransit. The study reviewed the different types of RT-DDS technology, functions, and business models. It also examined the technology's historical context and impact on transit services. Several research databases, such as the Transportation Research Record and the National Transportation Library, were used to gather relevant information. Past studies have revealed that adopting RT-DDS can effectively address paratransit routing/dial-a-ride problems (DARP). The study's findings will help transportation planners and policymakers select and adopt appropriate on-demand paratransit systems and improve service design and outcomes for paratransit and demand-responsive transit using RT-DDS.

### **2.1 Introduction**

Transit agencies are integrating real-time dynamic dispatching and scheduling technologies to improve paratransit services. These technologies enable efficient allocation methods and dynamic planning of trip requests based on current events such as traffic and weather (Acheampong et al.

(2020). The integration of real-time dynamic scheduling algorithms allows instant adjustments to be made, improving the performance of paratransit services (Rizos, 2010).

Integrating RT-DDS technology helps improve transit performance by allocating resources more efficiently. Studies have shown that ride-hailing services have created new trip demands while also reducing travel demands from public transit services (Acheampong et al., 2020; Rayle et al., 2016; Hasselwander et al., 2023; Hall et al., 2018; Lindsay, 2017). RT-DDS adoption in paratransit is challenging due to financial, strategic, organizational, and technical hurdles. Further research is necessary to evaluate new ridepooling algorithms. An RT-DDS connects users, drivers, and cloud-based systems through a dynamic dispatching rule generation mechanism, allowing riders to plan trips dynamically. This is discussed in Butler et al.'s (2021) study.

RT-DDS technology is transforming public transit by offering on-demand services like paratransit, microtransit, flex-routing, and ridesharing (Acheampong et al., 2020; Wilbur et al., 2023). Transit agencies and TNCs use app-based platforms to make transit more convenient and flexible (Circella & Alemi, 2018; Hall et al., 2018; Sadowsky & Nelson, 2017). Ridesharing services using RT-DDS technology address first and last-mile challenges in transit, increase ridership and provide flexible mobility solutions. RT-DDS technology can be utilized for on-demand paratransit, microtransit, and ridesharing services, complementing the existing public transit system (Acheampong et al., 2020; Butler et al., 2021; Rayle et al., 2016; Hall et al., 2018; Lindsay, 2017; Circella & Alemi, 2018; and Sadowsky & Nelson, 2017).

RT-DDS technology is a crucial tool in transit operations management that optimizes transit performance objectives by allocating resources among tasks within a given period. Studies have found that the availability of ride-hailing services can generate new trip demands while reducing travel demands from existing public transit services over time (Acheampong et al., 2020; Rayle et

al., 2016; Hasselwander et al., 2023; Hall et al., 2018; and Lindsay 2017). Nevertheless, several challenges exist, and significant financial, strategic, organizational, and technical challenges must be addressed. RT-DDS technology adoption processes in paratransit differ from implementing TNC ridesharing formulations for real-world conditions and constraints. More research is needed to evaluate new ridepooling algorithms and approaches in real-world paratransit settings. Therefore, exploring and understanding existing challenges requires a systematic literature review, which is crucial for an emerging research topic (Butler et al., 2021).

## **2.2 Purpose**

This paper aims to conduct a literature review describing the status of real-time dynamic dispatching and scheduling technologies in paratransit. As new transportation modes are being developed, this study seeks to comprehensively examine and document the current state of on-demand and demand-responsive transportation systems (RT-DDS) in paratransit. More research is required to understand the impacts of RT-DDS implementation, including its effects on transportation decisions and travel patterns. This information will help expand the knowledge base and enable transit agencies to navigate emerging changes in the transportation landscape and leverage new transit technologies and partnership opportunities. The findings of this study will aid transit planners and managers in comprehending the technology and serve as a basis for technology scoping studies.

## **2.3 Background Literature**

This section offers insights into the current challenges and developments within the paratransit industry. Additionally, it explores the fundamental principles of real-time dynamic dispatching and scheduling (RT-DDS) and how they apply in the context of paratransit and flexible

on-demand transit services across the United States. The text also presents findings from previous research on RT-DDS systems relevant to paratransit and flexible public transportation services.

### ***Paratransit and Demand-Responsive Transportation in Context***

Paratransit is a shared-ride service for disabled individuals that complements fixed-route transit (Miah et al., 2020). On-demand microtransit is a flexible service that uses vans or minibuses to transport passengers. It provides flexibility to paratransit operations through smartphone applications, allowing users to request real-time service (Riggs et al., 2022; Volinski, 2019). Demand-responsive transit includes paratransit, taxis, deviated fixed-route service, and hybrid services like microtransit (Ripplinger & Brand-Sargent, 2010). Paratransit is a specialized transportation service for seniors and people with disabilities who cannot use conventional public transportation (Ma et al., 2018; Shaheen & Chan, 2016). Transit agencies must provide an alternative paratransit form comparable to fixed-route service under the ADA regulations (Agatz et al., 2012; GAO, 2012; Lave & Mathias, 2000; Masoud & Jayakrishnan, 2017; Federal Transit Administration, 2023). Paratransit provides reserved service, flexible scheduling, and routing and accommodates the needs of eligible riders based on community needs. The scheduling and dispatching software that supports it requires several features to facilitate its operations, including passenger, driver, and administrative staff components.

### ***Matchmaking and Scheduling Optimization***

Paratransit scheduling and dispatching are intricate due to diverse requests and combinations of vehicle-to-trip matches. RT-DDS systems automate scheduling, data collection, and customer notifications using GPS-enabled platforms with advanced algorithms. These systems optimize vehicle routes to reduce travel distance and time, eliminating the need for human dispatchers and call-takers (Ho et al., 2018; Volinski, 2019). Popular examples of RT-DDS app-platform technology

include Uber, Lyft, Via, RideCo, Sparelab, and TransLoc. Cloud computing and other technological improvements have enabled paratransit services to function beyond an agency's premises, allowing for remote monitoring and real-time scheduling.

RT-DDS software technologies are best suited for transit agencies that want to provide on-demand mobility services, manage dispatchers, mobile applications for drivers and users, and streamline everyday operations. Optimizing technology systems can help increase operational capacity, reduce travel time, and maximize distance traveled (Ghoseiri et al., 2010; Kaufman et al., 2016; Shaheen & Chan, 2016). The technology helps transit agencies operate more efficiently while offering state-of-the-art services to their customers (Wilbur et al., 2023; Volinski, 2019).

### ***On-Demand Paratransit Services***

Many public transport scheduling and routing systems do not have an efficient dynamic ridesharing algorithm that can incorporate vehicle dispatch and routing for on-demand mobility. However, on-demand systems like same-day paratransit, microtransit, and dynamic ridesharing services are expected to have a more significant impact on the future of transportation. This allows passengers with similar itineraries or trips to share a ride (Sayarshad & Chow, 2017; Alonso-Mora et al., 2017; Lokhandwala & Cai, 2018). Transit agencies have adopted app-based platforms and mobility services using RT-DDS technologies, which support real-time trip requests and assignments for on-demand paratransit and microtransit services (Ghoseiri et al., 2010; Kaufman et al., 2016; Shaheen & Chan, 2016).

Real-time dynamic dispatching and scheduling can efficiently pool and use existing capacity to offer on-demand paratransit, micro-transit, and trip planning services through smartphone apps or mobile applications (Kaufman et al., 2016; Ghoseiri et al., 2010). These services have enabled transit agencies to overcome first- and last-mile public transit connection challenges, improving service

quality and making mobility options available for the elderly and disabled. According to Kaufman et al. (2016), applying new technological systems could make paratransit services more efficient and provide a better customer experience. In New York City, such upgrades could save the transit agency up to \$133 million annually. These enhancements enable flexible mobility options, including same-day paratransit and other on-demand service schemes. This will increase travel flexibility for riders to access new opportunities and destinations that traditional paratransit services cannot provide (KFH Group, 2008).

### ***What Are the Important Research Areas?***

Investigations on demand-responsive paratransit systems have been extensive, but only some have thoroughly analyzed the impact of technology. Transit agencies must identify if technology tools can help them achieve their operational goals. The process of determining needs and goals can be demanding, and agencies require assistance with technological decision-making due to the overwhelming number of new transit technology options available. Recent studies have focused on improving efficiency by understanding service providers' challenges in meeting demand. This research focuses on comprehending the challenges facing paratransit providers and how adopting RT-DDS technology solutions can help address the issues of increased demand, high costs, and competition from private mobility providers. This research also includes emerging business models, routing, and zoning structures that provide essential information to solve problems and make informed decisions. RT-DDS systems are becoming increasingly important to transit agencies as they attempt to serve passengers in the face of evolving technology. This study hypothesizes that transit agencies need RT-DDS technology systems to solve their scheduling and dispatch needs. While agencies are devoting resources to this pursuit, their implementation approaches are, in practice, limited and ineffective because of several organizational, resource, and technological constraints.

The limited implementation of RT-DDS technologies in paratransit can be attributed to a need for more explanatory documentation and knowledge about the technology's potential benefits. The concept of RT-DDS and the approaches to its adoption have been shrouded in uncertainties, which have acted as limiting factor (Jittrapirom et al., 2017). To gain an understanding of how RT-DDS works, transit agencies have invested considerable time and effort in creating and maintaining large and unmeaningful data sets of AVL and GTFS real-time feeds that hardly benefit the scheduling, dispatching, and routing processes in paratransit (Dara-Abrams, 2020). This paper aims to provide a comprehensive review of the current literature on RT-DDS (also known as dynamic routing) technology that can be adopted in paratransit to help alleviate existing constraints.

## **2.4 Research Questions**

This research study aims to provide answers to the following questions related to RT-DDS adoption in paratransit:

1. What are the current models, practices, and approaches used for RT-DDS adoption in paratransit?
2. What types of RT-DDS operating systems are available?
3. What are the benefits and functionalities of RT-DDS system adoption in paratransit?

## **2.5 Methods**

This study used a systematic methodology to analyze relevant literature from various sources, following a narrative review approach by Kankanamge et al. (2019) and Wee & Banister (2016). The process involved four steps, starting with a planning stage where research objectives were defined and examined. Data were collected, and the reviewed literature was classified into specific themes based on the works of Yigitcanlar et al. (2019) and Butler et al. (2021). The study

focused on real-time dynamic dispatching, scheduling, and identifying paratransit's adoption and technology impacts.

The first steps involved scoping and reviewing the literature on real-time dynamic dispatching and scheduling, transit technology implementation, and changes in paratransit business models. Data were collected using Google Scholar and online journal sources. In step two, information from scholars, transit agencies, and professional associations was researched. Keywords like paratransit scheduling, real-time technology, rideshare, ride-hailing, and advanced traveler information systems from software vendors were used to identify resources. In step three, news reports, blogs, and opinion articles were found by searching the internet to understand how the technology community perceives emerging technologies related to dispatching and scheduling, new mobility platforms, real-time scheduling and routing, and digital information formats in transit. The relevance of each source was evaluated by checking the titles, abstracts, and keywords against secondary criteria. This process was also supported by casual discussions with colleagues from different transit agencies about their experiences and opinions on RT-DDS technology. This group consisted of experts in transit operations, planning, and policy from various organizations such as Arlington Transit, DASH, Ride On Flex, D.C Neighborhood Connect, PGC Link, MTA Mobility, and OmniRide. These discussions are intended to gain insights, share resources, and learn more about incorporating RT-DDS technologies into transit operations. The data were gathered, and searches were conducted on September 11, 2019, June 14, 2020, December 15, 2022, and December 31, 2022. Figure 1 depicts the process for identifying and screening materials (Moher et al., 2016; Page et al., 2021; Li et al., 2021).

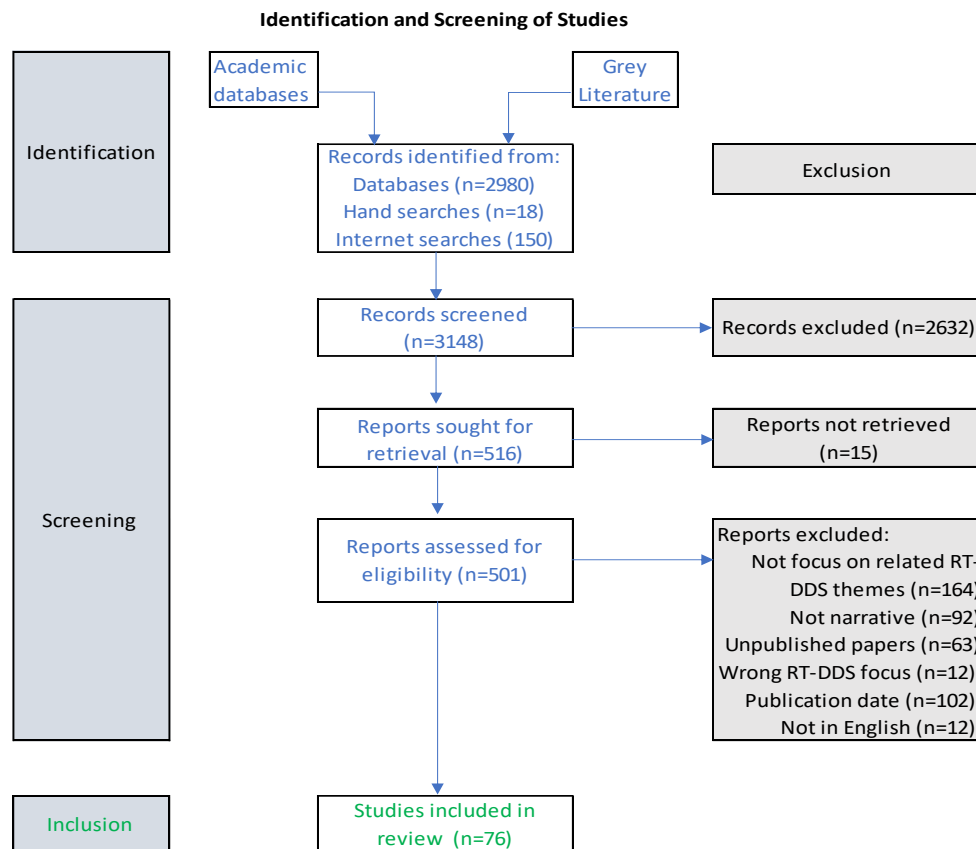


Figure 1- Identification and Screening of studies<sup>3</sup>

### ***Search Strategy and Selection Criteria***

This study used a systematic review approach, searching seven electronic databases containing over 10,000 journals published worldwide in English. The study focused on real-time scheduling, dispatching, and paratransit technology (Fisch & Block, 2018; Zupic & Cater, 2015). Sources included Web of Science, TRID, Journal of the Transportation Research Board, Journal of Public Transportation, Social Sciences Full Text, National Transportation Library, and USDOT Research Hub. The study examined RT-DDS and related business models using technical papers, reports, and white papers written by practitioners. Internet-based searches were conducted, and public transit publications were reviewed to identify current topics and emerging trends. Relevant

<sup>3</sup> Hand search includes the manual reviewing of resources and related research at work, in libraries, and at home.

literature was identified using keywords like real-time dispatching, routing optimization, and on-demand paratransit. Only English articles published after 2000 were included. Additional searches were guided by predefined criteria (see Table 1).

**Table 1. Exclusion and Inclusion Selection Criteria**

<i>Primary and Secondary Criteria</i>	<i>Exclusion Criteria</i>	<i>Inclusion Criteria</i>
<p>(1) Primary Criteria: Articles Peer-reviewed Full text available online</p> <p>(2) Secondary Criteria: RT-DDS-related materials relevant to research aims</p>	<p>(3) <i>Quantitative studies solely focus on a specific technology system or reports involving modeling or simulation.</i></p> <p>(4) <i>Studies that focus on a single technological attribute or are limited to a specific agency's need.</i></p> <p>(5) <i>Unpublished dissertations or thesis.</i></p> <p>(6) <i>Not a technical paper (e.g., describing algorithms without conveying facts or scientific opinion, policy, or practical implications of RT-DDS technologies).</i></p> <p>(7) <i>Studies not available in English.</i></p>	<p>(1) Studies from which a summary could be extracted, including articles, narrative reviews, synthesis, commentaries, editorials, etc., that focused on one (or multiple) of the five areas or conceptualization of RT-DDS:</p> <ul style="list-style-type: none"> <li>• real-time dynamic dispatching,</li> <li>• dynamic routing,</li> <li>• routing optimization,</li> <li>• DARP, and</li> <li>• on-demand paratransit</li> </ul> <p>(2) Full-text studies addressing real-time technologies in paratransit (and sub-fields, e.g., taxis, TNCs, ridesharing, microtransit) applications or technology systems in paratransit settings.</p> <p>(3) RT-DDS technologies studies should be addressed in either the (a) title and (b) abstract AND throughout the main body of work.</p> <p>(4) Secondary research synthesizes the literature or primary research involving quantitative or qualitative data that conveys a scientific opinion or empirical evidence.</p> <p>(5) Published in English or written in English.</p> <p>(6) The study is available in printed or downloadable form.</p>

**Data Extraction Analysis**

A predefined spreadsheet with column headers document's key themes and facts about real-time demand-driven shuttle technology. The data were validated and refined through internal reviews, and a qualitative thematic approach was used to synthesize the findings. Additionally, the selected studies were reviewed for additional terms, references, subject headings, and keywords to identify relevant papers that needed to be retrieved by the original search strategy (Butler et al.,

2021). Duplicate articles were removed, data were mapped, clustered into themes, and synthesized to provide a conceptual map of findings. The selection criteria for forming the themes are presented in Table 2.

***Table 2. Selection Criteria for Category Formulation***

The following approach was used to develop the main categories present in literature.

1. Detect technologies and attributes of adoptions for implementing RT-DDS technologies and systems in transit.
2. Detect RT-DDS systems for implementing paratransit and alternative services, including ridesharing for carpooling and vanpooling.
3. Identify potential adoption and implementation of RT-DDS systems in paratransit and other alternative services in transit.
4. Group the identified data based on similarities to form broader potential categories on RT-DDS-related primary sources and on-demand and shared mobility-related and public transit technologies.
5. Narrow down categories and check consistency against other literature.
6. Final review of literature and analysis of shortlisted categories.
7. Verify, classify, and finalize the creation of final categories.
8. Review the selected literature under the most relevant categories.

### ***The Reporting and Disseminating Stage***

Some 76 articles were identified during the literature review, and 17 additional articles were found through backward snowballing and recommendations from my dissertation committee.

Various methods were utilized to gather and document data, including electronic database searches, web-based searches through different interfaces, and hand searches. The initial search produced

3,148 results, comprising 2,980 references from database searches, 150 from internet searches, and 18 from hand searches. However, after screening through the titles and abstracts, 2,632 references were excluded. The full texts of 511 studies were then evaluated and analyzed. During this step, 411 studies were rejected, resulting in a final selection of 100 publications used in this study.

## **2.6 Literature Review**

### **2.6.1 The State-of-the-Art Practices in Paratransit**

#### *Dynamic Dispatching and Scheduling Systems in Paratransit*

Various forms of traditional transit dispatching and scheduling practices and new rideshare technology systems are available (National Center for Applied Transit Technology, 2021). Traditional practices include schedules, call centers, automated voice response systems, computer-aided dispatching, automated dispatching-and-routing technologies, and real-time dynamic dispatching and scheduling systems (Kaufman et al., 2016; Mandelbaum, 2003; Anton et al., 1999; Fu & Teply, 1999; Dial, 1995). Modern systems consist of ridesourcing services, on-demand carsharing, ridesharing, transportation network companies, and e-hailing services (Belz & Gårder, 2009; Rizos, 2010; Raman et al., 2003; Schweiger, 2011; RideCo et al.).

Automated vehicle location tech and scheduling systems can provide real-time trip data (APTA, 2010; Barbeau et al., 2014). This data includes time, location, and status and is readily accessible and highly reliable for many users (Jariyasunant et al., 2011). On-demand ridesharing dynamic dispatching and scheduling differs from traditional ridesharing services because they are arranged per trip (Casey et al., 2000). Twin Transit in Minnesota implemented an RT-DDS-powered rider app that allows riders to easily book demand response rides, freeing up booking agent capacity and availability (Dhanani, 2022).

## ***Components of RT-DDS System***

The available literature comprehensively discusses the features and functions of AVL/CAD systems (Khattak & Hickman, 1998; Dial, 1995). However, the integration of RT-DDS technology into paratransit has not been extensively studied, and there needs to be a more formal structure for its adoption (Khattak & Hickman, 1998; Hasselwander et al., 2023). With the rise of the shared economy, it has become necessary to use adaptive scheduling algorithms to ensure efficient resource allocation, real-time optimization, and communication while maintaining flexibility and responsiveness (Skobelev, 2015; Kalra et al., 2019). This research aims to classify the availability and deployment of real-time dynamic dispatching and scheduling technologies. Unlike traditional schedule-based systems in paratransit, the general architecture for real-time dynamic dispatching and scheduling technologies relies on real-time information, location-based data, predictive analytics, and mobile-application interfaces, which incorporate data from various sources (Jariyasunant et al., 2011; Khattak & Hickman, 1998). The success of these applications depends on multi-agent technology, which is essential for providing on-demand and real-time functionalities (Skobelev, 2015). A prototype system is based on five components outlined and illustrated in Table 3.

***Table 3. Five Components of the RT-DDS System***

<b><i>Feature</i></b>	<b><i>Function</i></b>	<b><i>Source</i></b>
Navigation/location	Location-based devices or services such as mobile devices, the internet, GPS, or cell tower based-based location technology. Other supported systems include Automatic Vehicle Location (AVL) systems and Computer-Aided Dispatch (CAD).	Jariyasunant et al. (2011); Khattak & Hickman (1998); Stone et al. (1992).
Communication mechanisms or technologies	Communication mechanism for transmitting location data from vehicles and passengers. Communication technologies can include smartphones, onboard computers, data terminals, etc.	Stone et al. (1992); Skobelev (2015).
Routing algorithm and matching technology	Algorithm for routing optimization that determines the K-shortest paths between an origin and destination based on traffic congestion and factoring rideshare requests.	Kaufman et al. 2016); Dial (1995); Skobelev (2015).

Cloud computing	Cloud computing is a computing model that distributes resources across a network of computing systems to deliver high-performance results. Users can access a shared pool of resources in real-time via the internet using their devices in a self-service, scalable, and metered manner. The objective is to allocate tasks to the most appropriate resources, optimizing objectives.	Kalra & Singh (2015).
Data Analytics	Third-party static and dynamic information providers	Welch & Widita (2019).

***History of Rideshare Systems and Technology***

Ride-hailing has its roots dating back to the 1950s when car-sharing clubs emerged in the United States (Chan and Shaheen, 2012). In the 1980s and 90s, dynamic sharing began as ridematching applications, but the lack of internet or telecommunication platforms hindered their success. The systems failed to attract enough users to create a consistent instant ride-sharing match. To address this, the next generation of ridesharing strategies focused on promoting ridesharing through online ridematching and traveler information services (Ghoseiri et al., 2010). Before 1999, ride-matching applications were usually websites or simple pages that displayed agency contact information, online forms to email the agency to receive a match list, or online notice boards for users to manually post or search carpool listings (c et al., 2010). From 1999 to 2004, private software companies started developing ridematching platforms (Ghoseiri et al., 2010; Chan and Shaheen, 2011). However, most online ridematching schemes were best suited for commutes with regular prearranged schedules, as these platforms were rigid and inflexible (Chan & Shaheen, 2011). In 2000, the Federal Communications Commission designated “511” as a uniform traveler information telephone number to provide real-time traveler information for local, regional, and state agencies across the U.S., including carpool and vanpool information services (Ghoseiri et al., 2010). Figure 2 shows the timeline of advancements relating to ride-sharing schemes and technologies.

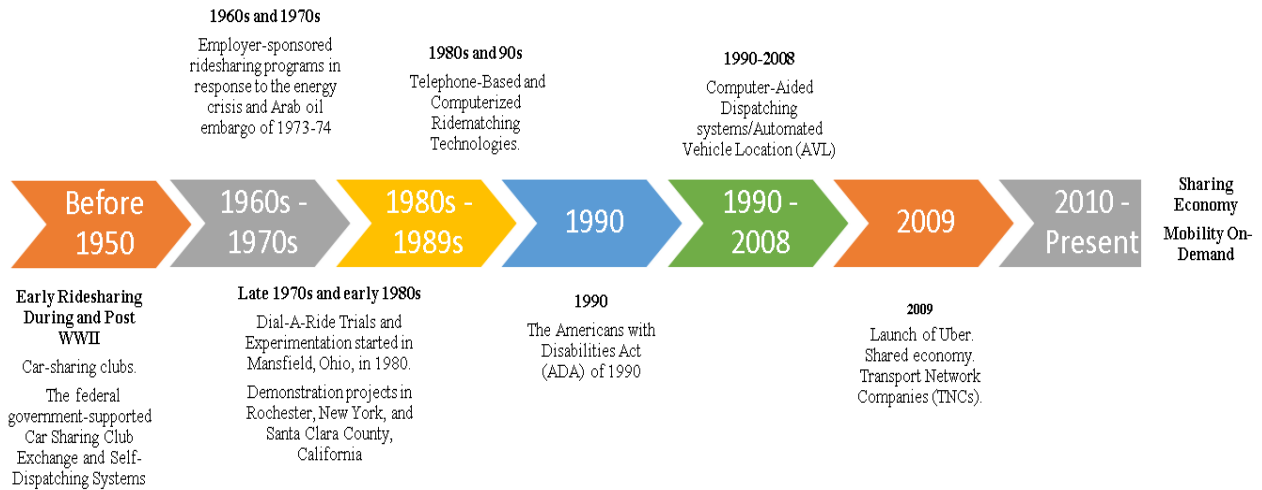


Figure 2 Timeline of Advancements Relating to Ride-Sharing Schemes & Technologies

### ***Early Ridesharing During and Post WWII***

Ridesharing started in the 1940s to save resources for the war effort. It resurfaced in the 1970s due to the energy crisis (Chan & Shaheen, 2012; Stone et al., 1994). Before 1973-1974, carpooling was minimal in the U.S. and focused on employment locations (Owens, 1981). Early carsharing programs were voluntary and only covered driver expenses (Chan & Shaheen, 2012; Owens, 1981). The government-supported Car Sharing Club Exchange and Self-Dispatching Systems were the predecessors to present-day carpooling systems. Current transit services use shared-ride algorithms (Columbia Law Review, 1942; OCD, 1942; Owens, 1981; Ordóñez et al., 2017).

### ***Employer-sponsored ridesharing programs (Between 1960 and 1970)***

Since 1974, the US Department of Transportation has sponsored community-based ridesharing to combat the fuel crisis (Owens, 1981). During the 1973-74 energy crisis and the Arab oil embargo, employer-sponsored ridesharing was developed, including vanpooling, casual carpooling, and technology systems, to provide cost and travel-time savings for drivers and passengers to counter high gas and energy costs (Owens, 1981; Shaheen & Cohen, 2019; Greenblatt

& Shaheen, 2015; Chan & Shaheen, 2012). In the 1970s, the US transit industry was evolving, and the ownership structure shifted from private to public (Talley & Anderson, 1986). The government began to provide capital and operating subsidies, leading to a rise in demand for demand-response paratransit. Before the shift, only fixed-route transit was available, with social service agencies providing paratransit. Paratransit services bridged the gap between fixed-route transit and the flexibility of single-occupant vehicles (Roos & Alschuler, 1975).

Dynamic routing was introduced in the 1970s before supporting technology was available (Roos & Alschuler, 1975). Dynamic ridesharing is a modern approach to ride-sharing among travelers. It enables them to plan and organize rides using their cell phones or computer messaging several days before the ride (Deakin et al., 2010). With the advancements in internet-enabled wireless technologies, global satellite systems, cloud computing, and data sharing, people increasingly use mobile applications to share rides (Shaheen & Cohen, 2019).

### ***Dial-A-Ride Trial and Experimentation Period (the late 1970s and early 1980s)***

Dial-a-Ride Transit (DRT) systems have existed in the United States for several decades. However, it was not until the advent of critical technological advancements in the Global Positioning System (GPS) and computing that the concept became more viable and user-friendly (Ghoseiri et al., 2010). The first on-demand public transit service trial, Dial-A-Ride, was initiated in Mansfield, Ohio, in the late 1970s and early 1980s. This allowed customers to make transport requests by phone (Ho et al., 2018). In the 1980s, Psaraftis (1980) developed a dynamic programming algorithm to allocate passengers for static and dynamic versions of Dial-A-Ride with a single vehicle (Ho et al., 2018). This led to large Dial-A-Ride demonstration projects in Rochester, New York, and Santa Clara County, California, among others (Aldaihani & Dessouky, 2003; Ho et al., 2018; Wilson et al., 1971; Stein, 1978; Psaraftis, 1980; Wang et al., 2022). A similar system was developed for

subscriber Dial-A-Ride systems in Baltimore, Maryland (Psaraftis, 1980). However, these early applications of new technology systems in Dial-A-Ride failed to meet expectations due to inadequate communication and computer technology to manage such systems effectively (Lave & Mathia, 2000).

### ***Telephone-Based and Computerized Ridematching (1980s and 1990s)***

Technologies for dial-a-ride for demand-responsive transit and commuter ridesharing were developed in different phases. In the 1980s and 1990s, new ride-matching systems were introduced. These systems offered various scheduling options such as phone, web-based, and computerized. Human operators, e-mail capabilities, automated interactive voice response (IVR) telephone systems, and the internet made these scheduling options possible. (Casey et al., 1996; Rizos, 2010). New automated systems for ride-matching using location information and maps were available in the 1990s. These included telephone-based options and enhanced ride-matching technologies that supported automated and user interfaces (Rizos, 2010; Ordóñez & Dessouky, 2017). Since 2004, digital technology has encouraged carpooling by partnering with public agencies and employers and offering incentives (Greenblatt & Shaheen, 2015; Chan & Shaheen, 2012).

Paratransit services were widely implemented between the 1970s and 1980s, leading to the Americans with Disabilities Act (ADA) in 1990. The ADA mandated comparable specialized transportation services for public transit agencies (GAO, 2012; Mulley & Nelson, 2006; Kaufman et al., 2016). However, regulatory challenges and high costs narrowed paratransit services to a small population that includes older adults and persons with disabilities or special needs, increasing the financial burden on transit agencies (GAO, 2012; Mulley & Nelson, 2006; Kane et al., 2016; Kaufman et al., 2016). In the 1980s and 1990s, the transit industry started adopting ridesharing technologies in paratransit to optimize and efficiently allocate resources and reduce operating costs. Ridematching schemes have incorporated information and communication technologies such as

mobile devices, cell phones, and social networking into their services since the late 1990s to expand their appeal and increase usage (Chan & Shaheen, 2012).

In the 1990s, specialized technology known as CAD/AVL was introduced in the paratransit industry. These computerized systems are used for booking, scheduling, and tracking paratransit trips (Rizos, 2010). From the late 1990s to 2008, ride-matching schemes like RT-DDS have integrated information and communication technologies like mobile devices, cell phones, and social networking into their services (Chan & Shaheen, 2012). They provide passengers with real-time tracking, estimated arrival times, and fare payment. However, they are expensive, outdated, and difficult to maintain (GAO, 2012; Kaufman et al., 2016).

### ***The Sharing Economy and Mobility On-Demand in the Era of Internet Enabling Technologies (2009-Present)***

Transport Network Companies (TNCs) have emerged in the past decade, leading to the evolution of Paratransit technology systems. Modern dispatching systems rely on real-time bus dispatching and advanced algorithms to allocate transit resources efficiently. These developments have become an essential element of modern dispatching systems, as highlighted by studies conducted by Gonzales (2019), Zhang et al. (2021), and Higgins (2000).

Ridesharing has become a popular way to connect with public transit, and there are now more opportunities to integrate ridesharing and public transit systems, as noted by Bian & Liu (2018). On-demand platforms are available for carsharing, ridesharing, and ridesourcing services, including transportation network companies such as UberX, Lyft, and Sidecar, as well as e-hailing services (Rizos, 2010; Raman et al., 2003; Schweiger, 2011; Belz & Gårder, 2009; RideCo et al.).

This convergence of shared mobility and transit points to the future of on-demand transit and RT-DDS technologies, supporting a modal split among public transit, shared fleets, and pooled rides

(Shaheen & Cohen, 2019). Various new business models have emerged and have been highlighted in studies by Kaufman et al. (2016), Feigon and Murphy (2016), Kane et al. (2016), and Murphy (2016). In 2016, the Massachusetts Bay Transportation Authority initiated a pilot program that offered travel subsidies to paratransit riders who used Uber, Lyft, and Curb. (Gonzales, 2019). Several other transit agencies have also established partnerships with mobility providers.

As shared-use transportation continues to evolve, it is crucial to keep up with the changing landscape by conducting new research in niche areas such as paratransit. In particular, understanding the scheduling problem that RT-DDS addresses is important as demand-responsive paratransit services evolve. Adopting new and emerging real-time data distribution service (RT-DDS) technologies for shared-use paratransit systems poses unique routing challenges due to complex business models. However, routing, and scheduling challenges in paratransit are often studied within the dial-a-ride problem (DARP) context.

## **2.6.2 The “Dial-A-Ride Problem” (DARP)**

Dial-a-ride is a paratransit system that offers on-demand transportation services using shared vehicles. Dial-a-ride problems (DARP) or scheduling problems can arise due to tight service time constraints, traffic congestion, unpredictable demands, and operating conditions (Cordeau et al., 2007; Fu, 2002; Ho et al., 2018). The challenge is to find cost-effective vehicle routes that balance demand and capacity while meeting trip request criteria. This has been highlighted in numerous studies such as Wang et al. (2022), Fu (2002), Liao & Hu (2011), Ghiani et al. (2003), and Hu et al. (2003).

DARP is a framework that addresses scheduling and routing deficiencies in the delivery of paratransit services. It optimizes vehicle routes, schedules travel times, and resolves routing conflicts to minimize operating costs (Ma et al., 2019; Hu et al., 2003; Ma et al., 2019; Weinreich et al., 2020;

Agatz et al., 2012). It also helps optimize fleet capacity and utilization. Several studies have shown that DARP can improve the efficiency of paratransit services (Gendreau et al., 1999; Ghiani et al., 2003; Psaraftis, 1995; Hu et al., 2003).

DARP logic and configuration schemes are embedded in the RT-DDS technology, which utilizes advanced algorithms to automate and customize vehicle routing and scheduling solutions while considering various constraints (Marković et al., 2015). The system can adjust and make tradeoffs between the level of service and system characteristics by utilizing real-time data. Every trip request involves three interconnected problems:

1. The booking and scheduling of trips is based on resource availability.
2. Assignment of trips by matching riders and drivers; and
3. Routing for ride-sharing services.

DARP helps understand paratransit challenges and how technology can address them. RT-DDS uses dynamic scheduling and routing optimization strategies to overcome DARP challenges by matching trip requests with appropriate vehicles at specific locations and times. This results in reduced wait time, travel distance, and increased efficiency. Studies have shown that DARP helps optimize fleet operations by minimizing operating costs and improving productivity (Hershey et al., 2010; Ma et al., 2019; Yan et al., 2020b; Richter et al., 2011; Thatcher et al., 1991).

### **2.6.3 Types of RT-DDS Technology**

RT-DDS technology can be classified based on its scheduling and routing approach. Li et al. (2022) identified several scheduling and routing approaches using a hierarchical approach in their research. These approaches include service options for one-to-one, many-to-many, few-to-few, few-to-one, and one-to-many directions based on customer preference. Ho et al. (2018) classified RT-

DDS services into three types based on trip requests and optimization algorithm results. Some transportation agencies are exploring innovative RT-DDS applications outlined in Table 4.

RT-DDS Technology can be categorized based on the type of scheduling and routing approach it implements. In their research, Li et al. (2022) used a hierarchical approach to identify several scheduling and routing approaches, including service options for one-to-one, many-to-many, few-to-few, few-to-one, and one-to-many directions based on customer preference. Ho et al. (2018) have categorized RT-DDS services into three types based on trip requests and optimization algorithm results. Some transportation agencies are exploring innovative RT-DDS applications outlined in Table 4.

**Table 4. Types of Real-time Dynamic Scheduling and Dispatching Technologies**

<b>Trip Type</b>	<b>Match Type</b>	<b>Example</b>
<b>Express or direct trip for a single rider</b>	One driver and one rider, such as a single taxi trip	UberX and Lyft
<b>Ridesharing/ridesplitting</b>	One driver and multiple passengers, such as ADA paratransit	Uber Pool, Lyft Shared, shared use on-demand paratransit
<b>Hybrid of express and ride-splitting</b>	It can be any combination of one driver to one rider or multiple passengers, such as an on-demand shuttle.	UberX or Uber Pool, Lyft, or Lyft Shared

Express matches are for solo passengers with one driver. Ridesplitting is for multiple passengers. Hybrid options combine express and ridesplitting. Services include call-and-ride and point-to-point options and are operated by private companies (Li et al., 2022; Yan et al., 2020b).

### ***An Evolving Landscape for Paratransit, On-Demand, and Demand Response Transit (DRT) Services***

*Paratransit* is a specialized transportation service that is meant to complement or supplement fixed-route transit and requires advance trip reservations (Thatcher et al., 1991; Wang et al. (2022)). RT-DDS adoption in paratransit could accelerate, given that 25.5 million people have travel-limiting disabilities, and 3.6 million individuals cannot leave their homes due to a lack of an affordable and

accessible transportation system (Brumbaugh, 2018). Current transportation data indicates that there is a significant latent demand for paratransit. However, many people who require this service cannot access it due to the lack of accessible transit (Mather et al., 2015). The paratransit landscape in the US is changing, and the literature has identified several key characteristics of this evolution.

### ***Recent Changes Affecting RT-DDS Adoption in Paratransit***

Paratransit demand is increasing fast in cities due to an aging population, and operating costs are expected to grow due to the unique requirements, such as door-to-door service options, technology needs, ADA-compliant vehicles, and specialized equipment (Lave & Mathias, 2000; Wang et al., 2022; Kaufman, 2016). Providing paratransit can cost several times more per trip than fixed-route services. Wang et al. (2022) found that in some US cities, the cost of delivering paratransit could be as high as \$70 per trip. New York City provides approximately six million paratransit rides annually (Jamison (2016). Transit agencies, planners, and policymakers face challenges determining which options work best for their demographics.

Providing paratransit services is a challenge that transit agencies often encounter. With advancements in information and communication technology, shared mobility options have become more feasible (Wang et al., 2022; Clewlow & Mishra, 2017). Transit agencies can now incorporate these systems into their operations through independent implementation or partnership with mobility service providers. However, the connection between paratransit service delivery and real-time dynamic dispatching and scheduling has not yet received sufficient attention.

Various studies have indicated that incorporating new technology, such as real-time dispatching and scheduling, can significantly enhance the delivery of paratransit services by boosting efficiency and flexibility. According to research conducted by Cordeau and Laporte (2007), on-demand transit systems and demand-response paratransit are closely related but differ in their

static and real-time algorithms. However, there has been limited investigation into the implementation of real-time technology in paratransit and how technological advancements are progressing in this field—for example, the increasing use of on-demand, ridesharing, and microtransit services. To effectively implement RT-DDS in on-demand and demand-responsive transport systems, it is essential to establish various option thresholds as initial planning objectives. Table 5 provides a comprehensive guide for implementing RT-DDS technologies in paratransit. These models and structured approaches are crucial in determining if RT-DDS suits an agency based on its strategic policy and planning objectives for technology adoption. Moreover, the table highlights alternative business models that can replace or supplement existing on-demand services. It is essential to evaluate these cases from a strategic, tactical, or operational perspective (Papanikolaou et al., 2017) before making any decisions.

**Table 5 RT-DDS Investment and DRT/Paratransit Business Models**

<i>Business Models for Paratransit Systems</i>	<i>Geographical Level</i>	<i>Existing Situation/Network</i>	<i>Success Criteria</i>	<i>Network Type</i>
Design a network of DRT lines to serve an area	Urban/Suburban/Rural level	Exists (or not) a network of an alternative transport mode (e.g., bus network)	Subsidy needs to be lower than the other modes	Network level – low demand, small scale
Substitute conventional service with paratransit service.	Urban/Suburban level	Already exists a bus service/line	The subsidy level needs to be lower than the other modes	Corridor level
Implement a new demand-responsive transit service.	Urban/Suburban level, special needs at urban level (people with disabilities, etc.)	There is no existing connection due to low demand	The subsidy level needs to be lower than the other modes	Corridor level

Source: Papanikolaou et al. (2017).

### ***Need for RT-DDS and Dynamic Routing in Paratransit***

Real-Time Dynamic Dispatching Systems (RT-DDS) are advanced routing technologies using heuristic programming and algorithms to enable high-level reservations and scheduling automation, on-demand services, and real-time dynamic planning and data analytics (Volinski, 2019;

Brake et al., 2006). Prior studies have investigated the feasibility of dynamic scheduling, dispatching, and routing systems as both theoretical concepts and actual implementations of RT-DDS (Périvier et al., 2021; Borole et al., 2013; Ghahramani & Brakewood, 2016; Liu & Miller, 2020; Siuhi & Mwakalonge, 2016). These studies concluded that RT-DDS is a viable concept that can help transit agencies reduce wait and travel times and minimize costs for operators and passengers (Fu et al., 2003; Jariyasunant & Sengupta, 2011). The need for RT-DDS arises from scheduling unreliability issues. Deploying RT-DDS can reduce waiting times for delayed transit vehicles and enable vehicles to take a faster alternative route (Jariyasunant et al., 2011). For instance, RT-DDS can be used to shift from traditional public transit to services such as ridesharing (e.g., UberPool), car-sharing (e.g., Poppy), and on-demand transit options or ride-hailing like Uber or Lyft (Melis & Sörensen, 2022).

Paratransit agencies increasingly use advanced technologies to expand their services and reduce operational costs. However, in practice, these technologies require addressing the context of intelligent transportation systems (ITS) for a greater chance of success. Dynamic routing and flexibility are critical for paratransit and core elements of RT-DDS technology systems. These systems can help minimize real-life routing problems through real-time optimization resources, considering travel time variations, unpredictable ridership demands, service interruptions, traffic congestions, and unpredictable safety and traffic events. RT-DDS allows for real-time decision-making and allocation of resources to accommodate unknown elements such as new trip requests and traffic conditions.

According to Ghahramani and Brakewood (2016), shared mobility services offer the advantage of real-time information accessibility for both transit riders and agencies. However, idle vehicle relocation is a significant issue, resulting in high operational costs for shared mobility

systems (Ma et al., 2019). Researchers suggest a state-of-the-art heuristic vehicle dispatching approach to reduce the overall system cost and average ride time compared to a myopic dynamic dispatch and routing. Idle vehicle relocation can be categorized into non-myopic and myopic methods. Non-myopic idle vehicle relocation focuses on single-operator systems independent of other operators, and previous studies have suggested different approaches for real-time optimal idle vehicle relocation or modeling idle vehicle rebalancing (Partridge et al., 2020; Fu, 2002; Guo et al., 2012). Conversely, myopic relocation considers passenger wait time, journey time, and vehicle trip lengths as an integrated performance measure.

### ***Scheduling and Dispatching Optimization***

Efficient demand-responsive transportation services require batching and optimization strategies. A study on dynamic ridesharing in Los Angeles found it viable (Hall & Qureshi, 1997; Ghoseiri et al., 2010). Mo et al. (2018) developed a scheduling model based on batching and optimization to balance pick-up and drop-off times and enable efficient scheduling. However, paratransit agencies face significant challenges managing their demand-responsive service for disabled riders without real-time systems. Challenges relate to demand, ridership, demand patterns, and supply-side considerations (Gonzales et al., 2019; Li et al., 2022).

RT-DDS application for batching and routing optimization has the potential to reduce costs by improving routing efficiency, minimizing factors like vehicle miles and time traveled per trip (Guo et al., 2021), and helping to adjust to demand uncertainty. On-demand mobility is increasingly popular as technology evolves (Greenblatt & Shaheen, 2015). RT-DDS solutions dispatch vehicles to pick up riders and transport them to their pre-defined destinations on the requested day (Circular 2710.2A, 1988). Regardless of the strategy and approach of adoption, whether it is on-demand paratransit, ridesharing, or microtransit, studies show that these systems increase accessibility and

flexibility, leading to lower user ride times, reduced waiting, and total travel distance (Yan et al., 2019; Melis & Sørensen, 2020; Tsao et al., 2019). Table 6 highlights the benefits of on-demand systems over traditional paratransit.

**Table 6. Summary and Comparison of On-demand and Traditional Paratransit Systems**

<b>RT-DDS – Operating Systems (On-demand transportation modes and systems)</b>	<b>Traditional Paratransit (ADA Paratransit)</b>
Door-to-door, curb-to-curb	Door-to-door
Single time window for pickup and drop-off	Separate time windows for pickup and drop-off
No maximum ride time constraint	Maximum ride time constraint
Quality-based objective: min. User ride time	Cost-based objective: minimize total distance driven
On-demand booking within 30 minutes of the actual time of travel	Advanced reservation and manual booking at least one day before travel
Rides are booked from an app, web portal, or by phone	Rides are booked by telephone or web portal
High demand and usage	Low demand

## 2.7 Discussion

Paratransit and demand-responsive services are becoming increasingly popular as they offer shared mobility options. Paratransit has become more efficient, cost-effective, and convenient by integrating location-based technologies, communication services, and automation such as algorithms, instant communication, and decision-making support systems (Kaufman, 2016; Shaheen & Cohen, 2020). Over the last decade, paratransit has shifted towards on-demand mobility business models and implementation practices. Two critical elements for RT-DDS adoption are business models for implementing and delivering on-demand transit services and technology implementation processes or practices. Municipalities, mobility providers, and public agencies must understand gaps and opportunities with new business models (Luckeneen, 2019). It is crucial to have performance mechanisms to evaluate the implementation of RT-DDS systems, ensuring that the adoption fully incorporates app-based platforms to deliver on-demand services that effectively address a

community’s mobility needs. A well-structured process for using performance outcomes to define service needs must be considered.

## 2.7.1 What are the current models, practices, and approaches used for RT-DDS adoption in paratransit?

### *Paratransit and On-Demand Transit Business Models*

A business model refers to an organization's approach to providing its services and maintaining its position in the market, including the overall strategy with its customers, suppliers of goods, and services it delivers to its customers (Chesbrough, 2007; Partridge et al., 2020). The business model of a transit agency involves its suppliers, providers, and customers, which can be either business-to-consumer (B2C) or business-to-government (B2G). Transit agencies and providers can assess the market by analyzing a business model and predicting, preparing, and adapting to changes (Partridge et al., 2020). According to a typology for Mobility-On-The Demand (MOD) developed by the FTA Sandbox Program, MOD has four business service models applicable to paratransit and on-demand transit services (Patel et al., 2022; Chesbrough, 2007; Partridge et al., 2020). MOD is a new concept that views transportation as a product that can be provided to consumers on demand through various strategies and four groups: service for people with disabilities, first/last mile solutions, mobile applications targeting one non-transit mode, and mobile applications integrating public and private transportation services in one app relevant to MOD business models. Table 7 shows MOD business models adjusted for paratransit and on-demand transit.

*Table 7 MOD Business Models for Paratransit and On-Demand Transit*

Business Model	How it Functions or Works	MOD Example and Implementation Approach
----------------	---------------------------	---

Brokerage <ul style="list-style-type: none"> <li>business-to-government (B2G)</li> </ul>	Bringing buyers and sellers together and charging fees per transaction to a party.	<ul style="list-style-type: none"> <li>Peer-to-peer carsharing</li> <li>Paratransit</li> </ul>
Bundling <ul style="list-style-type: none"> <li>business-to-government (B2G)</li> </ul>	Package related to goods and services together	<ul style="list-style-type: none"> <li>MaaS applications with a set fare and payment for original service</li> </ul>
Pay-as-you-go <ul style="list-style-type: none"> <li>business-to-consumer (B2C)</li> </ul>	Fares and fees charged for actual metered usage	<ul style="list-style-type: none"> <li>Ridesourcing</li> <li>Microtransit operators</li> </ul>
Product to Service <ul style="list-style-type: none"> <li>business-to-consumer (B2C) or business-to-government (B2G).</li> </ul>	Rather than sell a product, sell the service the product performs	<ul style="list-style-type: none"> <li>Microtransit (business-to-government partnership for technology-only operation)</li> <li>Peer-to-peer carsharing</li> </ul>

Source: Adapted from Partridge et al. (2020), Ovans (2015), and Johnson (2010).

These models are dynamic and are subject to policy, regulation, and competitive factors that can change the nature of the organizational business model over time (Partridge et al., 2020).

Apart from the discussed emerging business models, there are other formal strategies for mobility management available for traditional ADA-compliant paratransit and non-emergency medical transportation. These strategies include directly operated services by transit agencies and purchased transportation that involves different contracting and service management approaches (Mulley & Nelson, 2016). These include app-based ride services that connect commuters with private drivers using an online platform or mobile application (Patel et al., 2022).

**2.7.2 What types of RT-DDS operating systems are available?**

An operating system is a software platform that connects transit services and optimizes performance (Khan et al., 2013; Spieser et al., 2014). Transit agencies use Intelligent Transportation Systems (ITS) like RT-DDS, automated computer-aided dispatch, and automatic vehicle location to implement paratransit services efficiently. These platforms utilize operational data, including real-time data on vehicle location, passenger counts, traffic conditions, and electronic fare payment, to

optimize the delivery of transit services (Goldstein et al., 2016). Transit agencies also use data from these underlying operating systems to make informed decisions, understand customer behavior, and adjust services to meet customer needs (Marvin & Luque-Ayala, 2017). RT-DDS is one such platform that connects transportation elements to facilitate decision-making, coordination, and control while optimizing the size of the vehicle fleet deployed at different times of the day and reducing costs.

While implementation practices and use cases vary for these computerized technologies, there are four emerging RT-DDS operating systems, namely: Software-as-a-Service (SaaS), Transportation-as-a-Service (TaaS), Mobility-as-a-Service (MaaS), and Operator Partnership. These four operating frameworks can support any of the four business models identified. Table 8 shows RT-DDS operating systems, a system description, and examples.

**Table 8. RT-DDS Operating Systems**

<b>Operating Systems</b>	<b>Description</b>	<b>Example</b>	<b>References</b>
<b>Software-as-a-service (SaaS)</b>	SaaS is a model where technology is licensed to transit providers, while transit agencies use their resources, such as vehicles and drivers, to provide the services. The operating model of transit agencies may differ, but offering microtransit services through SaaS has become increasingly popular among riders and public agencies.	On-demand Paratransit, Microtransit Shuttle Bus	(Butler et al., 2021)
<b>Transportation-As-A-Service (TaaS)</b>	TaaS is a turnkey operational model where a transit technology provider provides technology solutions and operates service delivery on behalf of a transit agency, including hiring drivers, acquiring vehicles, and operations management.		(Ho et al., 2018)
<b>Mobility-As-A-Service (MaaS)</b>	The MaaS model comprises a single integrated and multimodal digital platform that aggregates and facilitates real-time travel or trip planning, wayfinding, arrival time predictions, and payment options for different transit services.	TransitApp, Uber, Lyft, Moovit	(Goulding & Kamargianni, 2018; Wong et al., 2020; Dzisi et al., 2022;

<b>Operator Partnership Model</b>	<p>The partnership model consists of a service delivery approach based on a contractual defined level of service and associated key performance measures. Contractual Partnerships can take different forms, such as peer-to-peer, business-to-consumer, or business-to-business, and contracts between transit agencies and mobility providers. Ride-hail and microtransit partnerships are popular Operator Partnership Models due to affordability, scalability, ridership potential, and high agency oversight. Formal partnerships through contracts can benefit both the transit agency and mobility providers by reducing operational costs, expanding customer base, and scaling operations.</p>	<p>Paratransit, Rideshare, Microtransit Partnerships, Ride-Hail Partnerships, and other types of app-based mobility services (e.g., taxis, TNCs)</p>
-----------------------------------	--	--

***Deployment and Implementation Strategies***

RT-DDS applications cover many transit software applications, including bus services, demand-responsive transit such as paratransit, taxis, and emerging on-demand transit services. These applications have customer-facing features such as map-based views of bus locations, schedule adherence, trip planning, self-service booking of demand-responsive trips, routing or navigation, fare payment, and ticketing. The agency also uses other operational software to manage its core services. There are various operational practices and approaches to RT-DDS adoption in transit. Operational practices in paratransit include dedicated vehicles owned and operated by transit agencies or providers and non-dedicated vehicles, TNC services, or taxis. The adoption of RT-DDS systems may impact the operational approach. Five operational practices and strategies are discussed below to highlight RT-DDS adoption, including on-demand paratransit, microtransit, ridesharing, and ride-sourcing (Partridge et al., 2020). Commingling is an emerging practice in adopting on-demand paratransit, providing multiple services using the same vehicle fleet and technology (N-CATT, 2021). Table 9 shows the different practices and approaches in paratransit.

*Table 9. RT-DDS Deployment and Implementation Schemes in Paratransit*

<b>Technology Adoption Strategies</b>	<b>Key Features</b>	<b>Sources</b>
<b>On-demand paratransit</b>	Flexible shared-use transit options for same-day transportation to ADA paratransit riders and the public in the general fixed route service the transit agency subsidizes.	(Kaufman et al. 2016; Murphy and Feigon, 2016; Shaheen & Cohen, 2020)
<b>Microtransit</b>	App-supported dynamic routing and technology-enabled shuttle services operated within well-defined zones or service areas.	(Rossetti et al., 2023; Shaheen et al., 2020; Westervelt et al., 2018; Luckenet al., 2019)
<b>Partnerships with TNCs or Ridesharing</b>	A key attribute of ride-sourcing companies (i.e., TNCs such as Uber and Lyft) platforms is that private companies own and operate these technology systems.	(Agatz et al., 2012; Ashkrof, et al., 2020; Melis & Sørensen, 2022; Hershey et al., 2010; Kauffman et al., 2016)
<b>Commingling</b>	An integrated services approach to delivering paratransit, microtransit, or alternative services using the same technology and vehicle fleet aiming to reduce the operating cost and increase the utilization of dial-a-ride vehicles.	(Ho et al., 2018; Westervelt et al., 2018; Butler et al., 2021)

On-demand paratransit (ODP) is an alternative and same-day transportation option for the public and ADA paratransit riders at subsidized fares offered by transit agencies. To provide on-demand and flexible shared-use transit service options, transit agencies are using new technologies and mobile applications or platforms for identical services and rider bookings (Kaufman et al., 2016; Ma et al., 2019; Murphy & Feigon, 2016). Microtransit services use demand-response, app-supported dynamic dispatching technology to match drivers and trips and route vehicles within well-defined service zones, typically involving minibuses or vans (Sadowsky & Nelson, 2017). Public agencies have implemented microtransit to address coverage gaps in historically underserved communities and provide first/last-mile solutions (Acheampong et al., 2020; Circella & Alemi, 2018; Hall et al., 2018).

To provide first/last-mile services such as micro-transit, transit agencies, and other public organizations increasingly partner with ridesharing companies such as TNCs and private mobility providers (Volinski, 2019). Ridesharing is a well-established public transit delivery and operations concept, including paratransit, fixed route bus, carpooling, vanpooling, and other services. It involves formal or informal ridesharing among drivers and passengers with similar origins and destinations, typically via digital applications. Ridesourcing is another term used to describe this phenomenon, which includes using digital mobility platforms provided by private vehicle owners to offer point-to-point, on-demand services to riders who request rides in real-time (Ashkrof et al., 2020). *Commingling* is an emerging practice that involves integrating services such as paratransit and microtransit with the same technology and vehicle fleet. Commingling allows for shared use of resources, reduces operational costs, and increases the utilization of dial-a-ride vehicles (Ho et al., 2018). These systems provide transportation services based on demand and address the needs of riders by offering seamless and efficient mobility solutions that often minimize and share costs (Ashkrof et al., 2020; Agatz et al., 2012; Melis & Sörensen, 2022).

### **2.7.3 What are the Benefits and Functionalities of RT-DDS System Adoption in Paratransit?**

#### ***RT-DDS System functionalities***

RT-DDS systems can be categorized into two groups: automating operational processes and optimizing dispatching in real-time. While the former replaces previously manual operations, the latter utilizes real-time data to allocate resources efficiently. Using an RT-DDS system offers faster and more accurate processing, but its primary advantage is the real-time dispatching automation. RT-DDS deployment varies among transit agencies and providers, depending on the type of transit vehicles and services offered (Goldstein et al., 2016). The functionalities of RT-DDS systems can

also vary based on the operating systems. Factors like agency size and customer base can influence the adoption of RT-DDS technologies (Goldstein et al., 2016; Partridge et al., 2020).

RT-DDS and paratransit software have significantly improved in the last decade, filling the “last mile” gap between transit stations and users’ destinations (APTA, 2010; Ecolane, 2022; GAO, 2012; Lava, 2008). They enable on-demand trip requests and real-time vehicle matching, considering traffic and trip demand (Čertický et al., 2014; Tai-Yu Ma et al., 2019). With the advancement in computing power and information and communication technologies, transit agencies have access to advanced technological systems like RT-DDS. These systems utilize automated and analytic tools such as artificial intelligence and machine learning to quickly analyze vast amounts of data. This results in more efficient resource allocation and optimization. Moreover, these systems offer integrated interfaces for tasks like trip planning, booking, scheduling, dispatching, vehicle routing, seamless fare payment, arrival predictions, communications, notifications, management dashboards, and more. The RT-DDS software includes several essential features and capabilities that benefit passengers and drivers. Thanks to advances in computing power, information technology, and communication, it is possible to access advanced technological systems like RT-DDS. These systems use automation and analytic tools, such as artificial intelligence and machine learning, to quickly analyze massive amounts of data. This allows for more efficient resource allocation and optimization. Moreover, these systems offer integrated interfaces for various tasks, such as trip planning, booking, scheduling, dispatching, vehicle routing, seamless fare payment, arrival predictions, communications, notifications, management dashboards, etc. The RT-DDS software includes several critical features and capabilities in addition to those for passengers and drivers.

### ***Benefits of RT-DDS***

RT-DDS has two significant advantages resulting from real-time data analytics and automated dispatching. These advantages include increased productivity and faster response time. To develop efficient allocation methods, algorithmic procedures based on operations research techniques are used to ensure the efficient allocation of resources. As a result, the successful implementation of RT-DDS technologies depends on the continuous growth of computing and cloud technologies and the innovative application of operations techniques through empirical research. The primary benefits of using an RT-DDS system lie in the real-time automation of the dispatching, scheduling, and routing processes, with the potential for significant cost savings. Systems with an administrative module empower agency staff to supervise and control daily operations and service configurations based on operational requirements.

The main objective of RT-DDS is to reduce operating costs, increase capacities, and improve the quality of service, such as wait time, ride time, and the time spent by passengers on buses (Melis & Sørensen, 2022; Ho et al., 2018). Dynamic dispatching and scheduling are potent tools for implementing strategies to help achieve optimization goals, such as minimizing costs by maximizing ride-sharing opportunities or ride-splitting to serve more passengers with limited resources. On the other hand, matching one passenger to one driver can offer more flexibility and reliability, increasing the service quality. Several studies have demonstrated the effectiveness of these strategies, including Wang and Yang (2019), Alonso-González et al. (2021), and Li et al. (2020). By adopting these technologies, transit agencies and mobility providers can improve operational efficiency, optimize resource allocation, and provide better service quality (Goldstein et al., 2016; Ho et al., 2018; Kaufman et al., 2016). Additionally, implementing these technologies can promote social equity and enhance service coverage.

Expanding service options such as microtransit, ridesharing, and on-demand paratransit can significantly benefit inclusion and social impact, especially for zero-vehicle households or individuals who cannot use private transportation due to lower incomes or disabilities. For decades, high operating costs and the “dynamic DARP” in paratransit have been significant barriers to expanding service. This challenge is caused by the need for more sophisticated scheduling and dispatching capabilities and the absence of enabling technologies designed to optimize operations, reduce costs, and improve efficiency.

Transit agencies must comply with ADA mandates to provide comparable services for disabled individuals unable to use fixed-route options (Hershey et al., 2010; Kaufman et al., 2016; Shaheen & Cohen, 2020). According to Volinski (2019), adopting the correct technology can enhance operational efficiencies, and cost savings are realized from RT-DDS implementation, allowing transit agencies to expand flexible travel options for paratransit services. RT-DDS solutions provide on-demand booking and dispatching of trips automatically based on dynamic optimization algorithms that will enable continuous re-optimization throughout the service day. RT-DDS systems are designed to replace human decision-making with advanced computer algorithms, enabling trip booking, dispatching, and routing automation using sophisticated routing models for converging trip requests, vehicle matchmaking, cancellations, and fares.

RT-DDS technology in transit can address coverage gaps in underserved communities and fill gaps in service left by inefficient bus services. It enhances resilience, reduces costs, and expands the scope of services (Volinski, 2019; Hall et al., 2018). RT-DDS solutions offer flexibility to customers by providing same-day trip scheduling and increasing travel options, making on-demand and door-to-door services more accessible. This minimizes transportation challenges disabled individuals face (Casey et al., 2018; Ho et al., 2018; Hall et al., 2018; Shaheen et al., 2017). RT-

DDS technologies and apps can also enhance the rider's experience, making it more enjoyable and efficient. Therefore, incorporating technology that caters to the context of paratransit, such as on-demand paratransit and microtransit, can minimize these challenges by giving riders the choice and flexibility to book their rides when it suits them the most. RT-DDS technologies and apps can also enhance rider experience, making it more enjoyable and efficient.

#### **2.7.4 Summary of Challenges Facing Paratransit Today**

Public transportation is becoming more inclusive and accommodating towards the diverse needs of riders. However, despite its significance, several obstacles must be overcome to ensure paratransit services are entirely accessible. As discussed in Chapter 1, the cost burden is a significant challenge for transit agencies, and the paratransit sector must address various issues that require innovative and effective solutions (Ecolane, 2022; Miah et al., 2019; National et al., 2018). Below is an outline of the significant challenges that need to be tackled in this regard:

- Growth in trip demand. The Americans with Disabilities Act (ADA), passed in 1990, has significantly increased demand for paratransit services in the United States. With a rise in the number of seniors, better medical care, and more opportunities for those with disabilities, there is a growing need for transportation options that cater to individuals who require mobility support (Mather et al., 2015; Miah et al., 2020; Lave & Mathias, 2000; Kaufman et al., 2016). Transit agencies must increase their operating capacity to enhance service frequency, expand their coverage areas, and respond promptly and efficiently to more trip requests. However, Ashour and Shen (2022) argue that the high operational costs associated with the rising demand for paratransit services pose significant challenges for transit agencies.

- Paratransit systems are facing financial challenges due to rising operating costs. The average cost of paratransit services has been increasing steadily. The average cost for an ADA paratransit trip in 2010 was \$29.30, a 10% increase from 2007 to 2010. However, the price has continued to increase, exceeding \$23 per trip in 2013. In NY, demand for paratransit is up five times since 2002 compared to subway ridership (Citizens Budget Commission, 2016; Kaufman et al., 2016). The New York City paratransit program spent \$472 million on 6 million rides in 2015, recovering only 4% from fares (Bertsimas & Yan, 2020). Chicago pays \$137 million annually and serves about 50,000 users, while MBTA in Boston spends \$75 million annually and serves 80,000 subscribers (Miah et al., 2020). Smaller paratransit systems, such as the one in San Mateo County, California, serve approximately 8,500 registered customers. The system costs over \$18 million annually, accounting for 12% of the agency's total operating expenses (Gee & Kersteen-Tucker, 2017).
- Coupled with the budget challenges, transit agencies have limited financial resources while meeting the increasing demand for services. Additionally, outdated technology systems and regulatory requirements add to their burden. To overcome these challenges, it is essential to implement scheduling and dispatching technological solutions to reduce operational costs and accommodate the growth in service demand. By adopting RT-DDS solutions, transit agencies can enhance their dispatching and routing technology systems, which could potentially address the issue of rising demand for paratransit service (Kauffman et al., 2016; Fu, 2001; Higgins, 2000; Lave & Mathias, 2000; Pagano et al., 2002).

The use of RT-DDS technologies in paratransit has increased, but transit agencies have faced difficulties in reducing costs and expanding services due to slow adoption (Kauffman et al. 2016).

Promising developments have occurred in cities such as San Francisco, Boston, Seattle, Washington DC, New York City, and Arlington, Texas, where public-private partnerships have been implemented using RT-DDS technologies to provide on-demand mobility services (Miah et al., 2020). Traditional ADA paratransit requires customers to schedule in advance, making it less flexible and efficient. Nonetheless, automated paratransit scheduling and dispatching technology can enhance the quality of paratransit service. This strategy has been recommended by various sources, including GAO (2012), Lave & Mathias (2000), Higgins (2000), Kane et al. (2016), Kaufman et al. (2016), Lave & Mathias (2000), and Pagano et al. (2002).

### ***Benefits of Real-Time Dynamic Dispatching and Scheduling***

In the future of transportation, on-demand systems such as same-day paratransit, microtransit, and dynamic ridesharing services will play a significant role. These systems rely on RT-DDS, which enables passengers with similar itineraries or trips to share a ride. This has been supported by numerous studies conducted by Sayarshad and Chow (2017), Alonso-Mora et al. (2017), and Lokhandwala and Cai (2018). The benefits of RT-DDS are summarized below.

- Using real-time demand-responsive dispatch systems can help address capacity constraints and allow transit systems to meet the expected growth in demand. RT-DDS automates dispatch, scheduling, routing, and trip booking while adjusting routes based on real-time traffic information. This technology is becoming more popular due to new software applications like artificial intelligence, smartphones, wireless communication devices, and driverless vehicles. These improvements are critical to the success of RT-DDS in paratransit. Numerous studies have shown the usefulness of RT-DDS in transit, including Alonso-Mora et al. (2017), Kauffman et al. (2016), Pandey et al. (2019), and Fielbaum et al. (2021).

- Incorporating RT-DDS technology can help solve problems related to scheduling and routing in transit systems. This could lower operating costs for paratransit services and help transit agencies accommodate the growing demand for transportation services. Several studies have shown the potential benefits of using RT-DDS, including those conducted by Kauffman et al. (2016), Hershey et al. (2010), and Richter et al. (2011).
- Transit agencies are utilizing new technologies to provide on-demand and flexible mobility options that reduce the cost of ADA paratransit trips and save agency resources. According to several studies (Casey et al., 2000; Fu, 2001; Ghoseiri et al., 2010; Liu et al., 2023; Kaufman et al., 2016; Masoud & Jayakrishnan, 2017), these technologies have proven effective. For instance, RT-DDS technology allows transit agencies to provide real-time data to their customers, such as route options, departure times, travel time, and wait time, enabling them to make informed travel decisions. A study completed by Sumalee and Ho (2018) supports the efficacy of this technology.
- These technologies also allow transit agencies to introduce on-demand and flexible mobility options that reduce more expensive ADA paratransit trips and save agency resources. Several transit agencies have implemented RT-DDS for microtransit and other alternative on-demand services, but successful RT-DDS systems and deployments in paratransit are limited (Ghoseiri et al., 2010; APTA, 2010; Lokhandwala & Cai, 2018).
- RT-DDS is a transportation system that should be accessible, safe, flexible, efficient, and cost-effective. It provides on-demand transit access, including curb-to-curb and door-to-door service. RT-DDS is popular with technology-savvy riders who prefer ease of use and access to real-time travel information and updates (Rizos, 2010). The system benefits

drivers and passengers by offering alternative and flexible transit modes, eliminating the need for additional transfer and travel time for their trip.

- Although some cost savings from RT-DDD implementation and pilot programs have yet to be documented, studies have shown that RT-DDS technology can optimize trip distances for riders using bus services with transfer points to complete a trip. This can reduce operating miles and increase trips per hour, significantly reducing travel time (Ecolane, 2023; Kaufman et al., 2016). RT-DDS deployment can also help combat the increase in vehicle trips and reduce average vehicle miles traveled and road congestion (Ghoseiri et al., 2010). These changes benefit drivers and passengers by providing alternative and flexible transit modes, eliminating the need for additional transfer and travel time for their trip. For instance, because most of the urban population in the United States does not live within one-quarter mile of a transit stop, the average commute to work is more than 35 minutes for an average trip, and there is a high cost for delivering paratransit (Weinreich et al., 2020).

## **2.8 Limitations**

This research highlights the need for more data on the implications of RT-DDS on established transportation business models. Understanding how transit agencies utilize RT-DDS and how it affects their routing and matching technologies is necessary. RT-DDS facilitates shared mobility service options using information technology. It is important to note that literature reviews provide a snapshot of a particular point in time, and the data collected during this study was primarily during the COVID-19 pandemic in 2021 and 2022. Therefore, the findings may not accurately represent any changes or shifts that have occurred since the pandemic, as new transportation patterns have emerged.

## 2.9 Conclusion

This research leverages a literature review across the paratransit and RT-DDS adoption spectrum to provide insight into the impacts of adopting real-time dynamic dispatching and scheduling on transit agencies. It outlines the issues and challenges facing implementing these new transportation technologies in paratransit, including reflections on the history and practice in this field and future directions. Most transit agencies and providers use computer-aided dispatch, automatic vehicle location, and other GIS systems for paratransit scheduling and dispatching. There has been a growth in the adoption of RT-DDS technology systems for paratransit and related on-demand services provided by mobility providers across the U.S. This trend is expected to continue as demand for paratransit trips increases as transit providers adopt new technologies and on-demand transit service options. RT-DDS offers greater flexibility to users; unlike traditional ride-sharing services like paratransit, taxi, carpooling, and vanpooling, which are arranged for regular trips, on-demand ridesharing is set per trip. This research finds that RT-DDS implementation offers significant value in enhancing operational efficiency. The results also suggest that the benefits of RT-DDS technology reach most riders, can reduce operating costs, improve system reliability, and reduce wait time and travel time. It was discovered that implementing RT-DDS and providing new on-demand services would require additional resources beyond the service contract. While technology adoption and implementation for RT-DDS technologies are continually evolving, current practices could be enhanced to reduce some of the challenges transit agencies face, such as cost constraints.

## 2.10 References

- Abdullah, M., Dias, C., Muley, D., & Shahin, M. (2020). Exploring the impacts of COVID-19 on travel behavior and mode preferences. *Transportation Research Interdisciplinary Perspectives*, 8, 100255.
- Acheampong, R. A., Siiba, A., Okyere, D. K., & Tuffour, J. P. (2020). Mobility-on-demand: An empirical study of internet-based ride-hailing adoption factors, travel characteristics, and mode substitution effects. *Transportation Research Part C: Emerging Technologies*, 115, 102638.
- Adamski, A. (2014). DISCON: Public transport dispatching robust control. *Procedia-Social and Behavioral Sciences*, 111, 1206-1216.
- Agatz, N., Erera, A., Savelsbergh, M., & Wang, X. (2012). Optimization for dynamic ride-sharing: A review. *European Journal of Operational Research*, 223(2), 295-303.
- Agatz, N., Erera, A., Savelsbergh, M., & Wang, X. (2010). Sustainable passenger transportation: Dynamic ride-sharing.
- Alonso-Mora, J., Samaranayake, S., Wallar, A., Frazzoli, E., & Rus, D. (2017). On-demand high-capacity ride-sharing via dynamic trip-vehicle assignment. *Proceedings of the National Academy of Sciences*, 114(3), 462-467.
- Ahmed, E., & Gharavi, H. (2018). Cooperative Vehicular Networking: A Survey. *IEEE Transactions on intelligent transportation systems: a publication of the IEEE Intelligent Transportation Systems Council*, 19(3), 996–1014. <https://doi.org/10.1109/TITS.2018.2795381>
- Arksey, H., & O'Malley, L. (2005). Scoping studies: towards a methodological framework. *International Journal of Social Research Methodology*, 8(1), 19-32.
- Ariyasunant, J., Mai, E., & Sengupta, R. (2011). Algorithm for finding optimal paths in a public transit network with real-time data. *Transportation Research Record*, 2256(1), 34-42.
- Artiba, A., & Elmaghraby, S. E. (Eds.). (1996). *The planning and scheduling of production systems: methodologies and applications*. Springer Science & Business Media.
- Anton, J., Bapat, V., & Hall, B. (1999). *Call center performance enhancement using simulation and modeling*. Purdue University Press.
- Ashkrof, P., de Almeida Correia, G. H., Cats, O., & Van Arem, B. (2020). Understanding ride-sourcing drivers' behavior and preferences: Insights from focus groups analysis. *Research in Transportation Business & Management*, 37, 100516.
- Ashour, L. A., Dannenberg, A. L., Shen, Q., Fang, X., & Wang, Y. (2021). Paratransit services for people with disabilities in the Seattle region during the COVID-19 pandemic: Lessons for recovery planning. *Journal of Transport & Health*, 22, 101115.
- Ashour, L. A., & Shen, Q. (2022). Incorporating ride-sourcing services into paratransit for people with disabilities: Opportunities and barriers. *Transport Policy*, 126, 355-363.

American Public Transportation Organisation (January 2021) [The Impact of the COVID-19 Pandemic on Public Transit Funding Needs in the U.S.](#)

American Public Transportation Association (n.d.). *Microtransit*. Retrieved September 17, 2023, from <https://www.apta.com/research-technical-resources/mobility-innovation-hub/microtransit/>

Avital, M., Andersson, M., Nickerson, J., Sundararajan, A., Van Alstyne, M., & Verhoeven, D. (2014). The collaborative economy: a disruptive innovation or much ado about nothing?.

Avital, M., Andersson, M., Nickerson, J., Sundararajan, A., Van Alstyne, M., Verhoeven, D.: The collaborative economy: a disruptive innovation or much ado about nothing? In: Proceedings of the 35th International Conference on Information Systems; ICIS 2014, Association for Information Systems. AIS Electronic Library (AISeL), Atlanta, GA, pp. 1–7 (2014)

Barbeau, S. J., Borning, A., & Watkins, K. (2014). OneBusAway multi-region–rapidly expanding mobile transit apps to new cities. *Journal of Public Transportation*, 17(4), 14-34

Belitski, M., Guenther, C., Kritikos, A. S., & Thurik, R. (2022). Economic effects of the COVID-19 pandemic on entrepreneurship and small businesses. *Small Business Economics*, 1-17.

Bertsimas, D., & Yan, J. (2020). The edge of optimization in large-scale vehicle routing for paratransit. Tech. rept. <https://dbertsim.mit.edu/pdfs/papers/2020-yan-transportation-scienceparatransit>. Pdf.

Berbeglia G, Cordeau JF, Laporte G (2010) Dynamic pickup and delivery problems. *European Journal of Operational Research* 202(1):8–15

Belz, N. P., & Gårder, P. E. (2009). Maine Statewide Deployment and Integration of Advanced Traveler Information Systems. *Transportation research record*, 2129(1), 16-23.

Birhanu, A. G., Getachew, Y. S., & Lashitew, A. A. (2022). Gender differences in enterprise performance during the COVID-19 crisis: do public policy responses matter?. *Entrepreneurship Theory and Practice*, 46(5), 1374-1401.

Bian, Z., & Liu, X. (2018, April). A detour-based pricing mechanism for first-mile ridesharing in connection with rail public transit. In *ASME/IEEE Joint Rail Conference* (Vol. 50978, p. V001T04A003). American Society of Mechanical Engineers.

Bliss, L. (2018, June 28). There is a Bus Driver Shortage. and No Wonder: Why Doesn't Anyone Want to Drive the Bus? CityLab. Retrieved January 19, 2022, from <https://www.bloomberg.com/news/articles/2018-06-28/there-s-a-bus-driver-shortage-and-no-wonder>.

Borole, N., Rout, D., Goel, N., Vedagiri, P., & Mathew, T. V. (2013). Multimodal public transit trip planner with real-time transit data. *Procedia-Social and Behavioral Sciences*, 104, 775-784

Brumbaugh, S. (2018). Travel patterns of American adults with disabilities. *Bureau Of Transportation Statistics, Washington DC, WA, USA, US Department of Transportation*.

Butler, L., Yigitcanlar, T., & Paz, A. (2021). Barriers and risks of Mobility-as-a-Service (MaaS) adoption in cities: A systematic review of the literature. *Cities*, 109, 103036.

- Casey, R. F., Labell, L. N., Moniz, L., Royal, J. W., Sheehan, M., Sheehan, T., ... & Parker, D. (2000). Advanced public transportation systems: The state-of-the-art update 2000.
- Casey, R. F., Labell, L. N., Holmstrom, R., LoVecchio, J. A., Schweiger, C. L. and Sheehan, T. (1996) Advanced Public Transportation Systems: The State of the Art, Update '96. Report No. FTA-MA-26-7007-96-1 (Washington, DC: FTA, US Department of Transportation).
- Chan, N. D., & Shaheen, S. A. (2012). Ridesharing in North America: Past, present, and future. *Transport reviews*, 32(1), 93-112. [Wayback Machine \(archive.org\)](#)
- Chesbrough, H. (2007). Business model innovation: it's not just about technology anymore. *Strategy & leadership*, 35(6), 12-17.
- Chia, D. (2008). *Policies and practices for effectively and efficiently meeting ADA paratransit demand* (No. 74). Transportation Research Board
- Citizens Budget Commission (CBC) (2016, September 12). *ACCESS-A-RIDE Ways to Do the Right Thing More Efficiently*. The Citizens Budget Commission (CBC). Retrieved September 17, 2023, from [https://cbcny.org/sites/default/files/REPORT\\_ACCESS-A-RIDE\\_09202016.pdf](https://cbcny.org/sites/default/files/REPORT_ACCESS-A-RIDE_09202016.pdf)
- Clewlow, R. R., & Mishra, G. S. (2017). Disruptive transportation: The adoption, utilization, and impacts of ride-hailing in the United States.
- Cochran, A. L. (2020). Impacts of COVID-19 on access to transportation for people with disabilities. *Transportation research interdisciplinary perspectives*, 8, 100263.
- Cordeau, J.-F. and Laporte, G. (2007). The dial-a-ride problem: models and algorithms. *Annals of operations research*, 153(1):29-46.
- Cordeau, J. F. (2006). A branch-and-cut algorithm for the dial-a-ride problem. *Operations Research*, 54(3), 573-586
- Dara-Abrams, D. (2020). *An Open Platform for Transit Agencies to Improve the Quality of Their Real-Time Data* (No. Transit IDEA Project 93).
- Davis, K. C. (1942). Dean Pound and Administrative Law. *Columbia Law Review*, 42(1), 89-103.
- Deakin, E., Frick, K. T., & Shively, K. M. (2010). Markets for dynamic ridesharing? Case of Berkeley, California. *Transportation Research Record*, 2187(1), 131-137.
- Deng, T., & Nelson, J. D. (2013). Bus Rapid Transit implementation in Beijing: An evaluation of performance and impacts. *Research in Transportation Economics*, 39(1), 108-113.
- Dhanani, J. (2022, September 13). *Twin Transit launches rider app for demand-responsive services in Lewis County*. <https://sparelabs.com/>. Retrieved October 10, 2022, from [https://sparelabs.com/en/blog/twin-transit-launches-rider-app-for-demand-responsive-services-in-lewis-county?utm\\_medium=email&\\_hsmi=226336644&\\_hsenc=p2ANqtz-9iehxzmjMHc6b0eurMZ-V1gR-GHkuAEVB-wGRvkBdG4HGAW368IJGvN6QrNfl837J2fW608NiC-hN02JWmrbUkYiplw&utm\\_content=226336644&utm\\_source=hs\\_email](https://sparelabs.com/en/blog/twin-transit-launches-rider-app-for-demand-responsive-services-in-lewis-county?utm_medium=email&_hsmi=226336644&_hsenc=p2ANqtz-9iehxzmjMHc6b0eurMZ-V1gR-GHkuAEVB-wGRvkBdG4HGAW368IJGvN6QrNfl837J2fW608NiC-hN02JWmrbUkYiplw&utm_content=226336644&utm_source=hs_email)

- Dial, R. B. (1995). Autonomous dial-a-ride transit introductory overview. *Transportation Research Part C: Emerging Technologies*, 3(5), 261-275.
- Downey, L., Fonzone, A., Fountas, G., & Semple, T. (2022). The impact of COVID-19 on future public transport use in Scotland. *Transportation Research Part A: Policy and Practice*, 163, 338-352.
- Dzisi, E. K. J., Obeng, D. A., Ackaah, W., & Tuffour, Y. A. (2022). MaaS for paratransit minibus taxis in developing countries: A review. *Travel Behaviour and Society*, 26, 18-27
- Eckert, R. D. (1978). Para-Transit: Neglected Options for Urban Mobility.
- Echaniz, E., Cordera, R., Rodriguez, A., Nogués, S., Coppola, P., & Dell'Olio, L. (2022). Spatial and temporal variation of user satisfaction in public transport systems. *Transport Policy*, 117, 88-97.
- Ecolane (2023, January 1). *3 Challenges in Paratransit and How to Solve Them*. [www.ecolane.com](http://www.ecolane.com). Retrieved September 17, 2023, from <https://www.ecolane.com/blog/3-challenges-in-paratransit-and-how-to-solve-them>
- Erhardt, G. D., Hoque, J. M., Goyal, V., Berrebi, S., Brakewood, C., & Watkins, K. E. (2022). Why has public transit ridership declined in the United States?. *Transportation research part A: policy and practice*, 161, 68-87.
- Falconer, R., Zhou, T., Felder, M. (2018). Mobility-as-a-Service: The value proposition for the public and our urban systems. MaRS Discovery District. <https://taf.ca/mobility-service-urban-systems/>
- Federal Transit Administration (2023, September 20). *Dear Colleague Letter: FTA Highlights Grant Programs that Support Real-time ADA Paratransit Service*. <https://www.Transit.dot.gov/>. Retrieved October 8, 2023, from <https://www.transit.dot.gov/regulations-and-programs/dear-colleague-letters/dear-colleague-letter-fta-highlights-grant-programs>
- Feigon, S., and Murphy, C. (2016). Shared Mobility and the Transformation of Public Transit. TCRP Research Report 188. Transportation Research Board, Washington, D.C.
- Feigon, S & Murphy, C. (2018). TCRP Research Report 195: Broadening Understanding of the Interplay among Public Transit, Shared Mobility, and Personal Automobiles. Transportation Research Board Transit Cooperative Research Program. <http://www.trb.org/Main/Blurbs/177112.aspx>
- Feigon, S., & Murphy, C. (2016). Shared mobility and the transformation of public transit (No. Project J-11, Task 21).
- Fielbaum, A., Bai, X., & Alonso-Mora, J. (2021). On-demand ridesharing with optimized pick-up and drop-off walking locations. *Transportation research part C: emerging technologies*, 126, 103061.
- Fielding, G. J. (1975). Demand-responsive transit: an overview of integrated systems. *Transportation*.
- Fisch, C., & Block, J. (2018). Six tips for your (systematic) literature review in business and management research. *Management Review Quarterly*, 68(2), 103–106
- Fu, L. (1999). Improving paratransit scheduling by accounting for dynamic and stochastic variations in travel time. *Transportation Research Record*, 1666(1), 74-81.

- Fu, L. (2001). Simulation model for evaluating intelligent paratransit systems. *Transportation Research Record*, 1760(1), 93-99.
- Fu, L. (2001). An adaptive routing algorithm for in-vehicle route guidance systems with real-time information. *Transportation Research Part B: Methodological*, 35(8), 749-765.
- Fu, L., & Teply, S. (1999). On-line and off-line routing and scheduling of dial-a-ride paratransit vehicles. *Computer-Aided Civil and Infrastructure Engineering*, 14(5), 309-319.
- Fu, L. (2002). Scheduling dial-a-ride paratransit under time-varying, stochastic congestion. *Transportation Research Part B: Methodological*, 36(6), 485-506.
- Fu, L., & Xu, Y. (2001). Potential effects of automatic vehicle location and computer-aided dispatch technology on paratransit performance: a simulation study. *Transportation Research Record*, 1760(1), 107-113.
- Fu, L., Liu, Q., & Calamai, P. (2003). Real-time optimization model for dynamic scheduling of transit operations. *Transportation research record*, 1857(1), 48-55.
- Furuhata M, Dessouky M, Ordóñez F, Brunet ME, Wang X, Koenig S (2013) Ridesharing: The state-of-the-art and future directions. *Transportation Research Part B: Methodological* 57:28–46.
- Garaix, T., Artigues, C., Feillet, D., & Josselin, D. (2011). Optimization of occupancy rate in dial-a-ride problems via linear fractional column generation. *Computers & Operations Research*, 38(10), 1435-1442.
- Gkiotsalitis, K., & Cats, O. (2021). Public transport planning adaptation under the COVID-19 pandemic crisis: literature review of research needs and directions. *Transport Reviews*, 41(3), 374-392.
- Ghahramani, N., & Brakewood, C. (2016). Trends in mobile transit information utilization: An exploratory analysis of transit app in New York City. *Journal of Public Transportation*, 19(3), 139-160.
- Ghoseiri, K., Haghani, A., & Hamed, M. (2010). Real-time rideshare matching problem (No. UMD-2009-04). Mid-Atlantic Universities Transportation Center. <https://rosap.ntl.bts.gov/view/dot/25988>
- Graehler, M., Mucci, R. A., & Erhardt, G. D. (2019, January). Understanding the recent transit ridership decline in major US cities: Service cuts or emerging modes. In *98th Annual Meeting of the Transportation Research Board, Washington, DC*.
- Goldstein, M., Zimmerman, S., Ashley, J., Bhatia-Sabharwal, N., Dor, A., MacLeod, H., ... & United States Government Accountability Office. (2016). *Intelligent Transportation Systems: Urban and Rural Transit Providers Reported Benefits but Face Deployment Challenges*.
- Guo, X., Caros, N. S., & Zhao, J. (2021). Robust matching-integrated vehicle rebalancing in ride-hailing system with uncertain demand. *Transportation Research Part B: Methodological*, 150, 161-189.
- Hall, J. D., Palsson, C., & Price, J. (2018). Is Uber a substitute or complement for public transit? *Journal of Urban Economics*, 108, 36-50.
- Hall, R. W., & Qureshi, A. (1997). Dynamic ride-sharing: Theory and practice. *Journal of Transportation Engineering*, 123(4), 308-315.

- Hasselwander, M., Nieland, S., Dematera-Contreras, K., & Goletz, M. (2023). MaaS for the masses: Potential transit accessibility gains and required policies under Mobility-as-a-Service. *Multimodal Transportation*, 2(3), 100086.
- Hassol, Joshua, David Perlman, Lora Chajka-Cadin, and Jingsi Shaw, "Understanding Surveys of Public Sentiment Regarding Automated Vehicles: Summary of Results to Date and Implications of Past Research on the Dynamics of Consumer Adoption," USDOT Intelligent Transportation Systems Joint Program Office, November 2019, FHWA-JPO-19-764. <https://rosap.ntl.bts.gov/view/dot/43628>.
- Ho, C. Q., Hensher, D. A., Mulley, C., & Wong, Y. Z. (2018). Potential uptake and willingness-to-pay for Mobility as a Service (MaaS): A stated choice study. *Transportation Research Part A: Policy and Practice*, 117, 302-318.
- Ho, S. C., Szeto, W. Y., Kuo, Y. H., Leung, J. M., Petering, M., & Tou, T. W. (2018). A survey of dial-a-ride problems: Literature review and recent developments. *Transportation Research Part B: Methodological*, 111, 395-421.
- Hu, S., & Chen, P. (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.
- Jamison, D. (2016). Access-A-Ride Ways to Do the Right Thing More Efficiently. *Citizen Budget Commission*, 20
- Jariyasunant, J., Mai, E., & Sengupta, R. (2011). Algorithm for finding optimal paths in a public transit network with real-time data. *Transportation research record*, 2256(1), 34-42.
- Jariyasunant, J., Work, D. B., Kerkez, B., Sengupta, R., Glaser, S., & Bayen, A. (2011). Mobile transit trip planning with real-time data.
- Kane, J., Tomer, A., & Puentes, R. (2016). How Lyft and Uber can improve transit agency budgets. *Metropolitan Infrastructure Initiative*.
- Kankanamge, N., Yigitcanlar, T., Goonetilleke, A., & Kamruzzaman, M. (2019). Can volunteer crowdsourcing reduce disaster risk? A systematic review of the literature. *International journal of disaster risk reduction*, 35, 101097.
- Kaufman, S. M., Smith, A., O'Connell, J., & Marulli, D. (2016). Intelligent paratransit.
- Lashitew, A. A. (2023). When businesses go digital: The role of CEO attributes in technology adoption and utilization during the COVID-19 pandemic. *Technological Forecasting and Social Change*, 189, 122324.
- Lave, R., & Mathias, R. (2000). State of the Art of Paratransit. *Transportation in the New Millennium*, 478, 1-7.
- Levac, D., Colquhoun, H., & O'Brien, K. K. (2010). Scoping studies: advancing the methodology. *Implementation Science*, 5, 1-9.
- Li, T., & Cavusgil, S. T. (1995). A classification and assessment of research streams in international marketing. *International Business Review*, 4(3), 251-277.

- Li, X., Ma, J., Cui, J., Ghiasi, A., & Zhou, F. (2016). Design framework of large-scale one-way electric vehicle sharing systems: A continuum approximation model. *Transportation Research Part B: Methodological*, 88, 21-45.
- Li, Y., Shan, B., Li, B., Liu, X., & Pu, Y. (2021). Literature review on the applications of machine learning and blockchain technology in smart healthcare industry: a bibliometric analysis. *Journal of Healthcare Engineering*, 2021.
- Li, X., Yuen, K. F., Wang, X., & Wong, Y. D. (2021). Contactless technologies adoption during the coronavirus pandemic: a combined technology acceptance and health belief perspective. *Technology analysis & strategic management*, 1-14.
- Lindsay, G. (2017). What if Uber kills off public transport rather than cars? *The Guardian*.
- Liu, L., & Miller, H. J. (2020). Does real-time transit information reduce waiting time? An empirical analysis. *Transportation Research Part A: Policy and Practice*, 141, 167-179.
- Liu, L., Porr, A., & Miller, H. J. (2023). Realizable accessibility: evaluating the reliability of public transit accessibility using high-resolution real-time data. *Journal of Geographical Systems*, 25(3), 429-451
- Los Angeles Department of Transportation (2019, August 23). *LADOT TAXI AND FOR-HIRE VEHICLE STUDY*. <https://Ladot.Lacity.org/>. [https://ladot.lacity.org/sites/default/files/documents/ladot-taxi-and-fhv-final-report-draft-for-distribution\\_0.pdf](https://ladot.lacity.org/sites/default/files/documents/ladot-taxi-and-fhv-final-report-draft-for-distribution_0.pdf)
- Lokhandwala, M., & Cai, H. (2018). Dynamic ride sharing using traditional taxis and shared autonomous taxis: A case study of NYC. *Transportation Research Part C: Emerging Technologies*, 97, 45-60.
- Lucken, E., Frick, K. T., & Shaheen, S. A. (2019). "Three Ps in a MOD:" Role for mobility on demand (MOD) public-private partnerships in public transit provision. *Research in Transportation Business & Management*, 32, 100433.
- Ma, T. Y., Rasulkhani, S., Chow, J. Y., & Klein, S. (2019). A dynamic ridesharing dispatch and idle vehicle repositioning strategy with integrated transit transfers. *Transportation Research Part E: Logistics and Transportation Review*, 128, 417-442.
- Marvin, S., & Luque-Ayala, A. (2017). Urban operating systems: Diagramming the city. *International Journal of Urban and Regional Research*, 41(1), 84-103.
- Masoud, N., & Jayakrishnan, R. (2017). A real-time algorithm to solve the peer-to-peer ride-matching problem in a flexible ridesharing system. *Transportation Research Part B: Methodological*, 106, 218-236.
- Mather, Mark, Linda A. Jacobsen, Kevin M. Pollard. 2015. *Population Bulletin: Aging in the United States*. Population Reference Bureau.
- Marković, N., Nair, R., Schonfeld, P., Miller-Hooks, E., & Mohebbi, M. (2015). Optimizing dial-a-ride services in Maryland: benefits of computerized routing and scheduling. *Transportation Research Part C: Emerging Technologies*, 55, 156-165.

- Melis, L., & Sørensen, K. (2022). The real-time on-demand bus routing problem: The cost of dynamic requests. *Computers & Operations Research*, 147, 105941.
- Melis, L. and Sørensen, K. (2020). The on-demand bus routing problem: A large neighborhood search heuristic for a dial-a-ride problem with bus station assignment. Working papers, University of Antwerp, Faculty of Business and Economics.
- Mandelbaum, A. (2003). Call centers (centres): Research bibliography with abstracts. *Version*, 3, 137.
- Model, N. (1990, October). Automated Paratransit Routing and Scheduling Using a Highway. In *Proceedings of a Conference* (p. 15).
- Murphy, C. M., & Feigon, S. F. (2016). Shared mobility and the transformation of public transit (n.d.). (2010, October 1). *Bus Rapid Transit Service Design*. APTA. Retrieved September 5, 2023, from [https://www.Apta.Com/wp-content/uploads/Standards\\_Documents/APTA-BTS-BRT-RP-004-10.Pdf](https://www.Apta.Com/wp-content/uploads/Standards_Documents/APTA-BTS-BRT-RP-004-10.Pdf).
- Miah, M. M., Naz, F., Hyun, K. K., Mattingly, S. P., Cronley, C., & Fields, N. (2020). Barriers and opportunities for paratransit users to adopt on-demand micro transit. *Research in transportation economics*, 84, 101001.
- Michalk, W., & AG, B. (2015). Evaluating services in mobility markets: A business model approach. In Service Summit Research Workshop-Advances in Service Research (p. 43). Karlsruhe Service Research Institute. <https://d-nb.info/1068855339/34#page=57>
- Moher, D., Stewart, L., & Shekelle, P. (2016). Implementing PRISMA-P: recommendations for prospective authors. *Systematic reviews*, 5, 1-2.
- Monahan, T., & Lamb, C. G. (2022). Transit's downward spiral: Assessing the social-justice implications of ride-hailing platforms and COVID-19 for public transportation in the US. *Cities*, 120, 103438.
- Mulley, C., & Nelson, J. D. (2016). Shaping the new future of paratransit: An agenda for research and practice. *Transportation Research Record*, 2542(1), 17-24.
- National Express Transit (2018, March 14). *THE 3 BIGGEST CHALLENGES FACING PARATRANSIT TODAY*. Retrieved September 17, 2023, from <https://www.nationalexpresstransit.com/blog/the-3-biggest-challenges-facing-paratransit-today/>
- National Center for Applied Transit Technology (2021, March 1). *A Guidebook on New Software Adoption for Small Transit Agencies*. <https://N-Catt.org/>. [https://n-catt.org/wp-content/uploads/2021/06/NCATT\\_Software-Guidebook.pdf](https://n-catt.org/wp-content/uploads/2021/06/NCATT_Software-Guidebook.pdf)
- Naz, F., Hyun, K., & Mattingly, S. (2019). Characterizing Paratransit and Micro-Transit Users: Understanding the Scope of Alternative Mobility Option for Older Adults through Mode Shift. *Journal of Transport & Health*, 14, 100635.
- Newell, G. F., & Potts, R. B. (1964). Maintaining a bus schedule. In *Australian Road Research Board (ARRB) Conference, 2nd, 1964, Melbourne* (Vol. 2, No. 1).

- Nguyen-Hoang, P., & Yeung, R. (2010). What is paratransit worth? *Transportation research part A: policy and practice*, 44(10), 841-853.
- Khan, A. N., Kiah, M. M., Khan, S. U., & Madani, S. A. (2013). Towards secure mobile cloud computing: A survey. *Future generation computer systems*, 29(5), 1278-1299.
- Kirby, R F, Bhatt, K U, Kemp, M A, McGillivray, R G, & Wohl, M. (1974). Para-transit: neglected options for urban mobility. United States.
- Kirby, R. F. (1974). *Para-transit: A Summary Assessment of Experience and Potential* (No. UMTA-CA-06-0045-71-1).
- Kuo, Y. H., Leung, J. M., & Yan, Y. (2022). Public transport for smart cities: Recent innovations and future challenges. *European Journal of Operational Research*.
- Ordóñez, F., & Dessouky, M. M. (2017). Dynamic ridesharing. In *Leading developments from INFORMS communities* (pp. 212-236). INFORMS.
- Owens Jr, D. D. (1981). Ridesharing programs: Governmental response to urban transportation problems. *Environment and Behavior*, 13(3), 311-330.
- Pagano, A. M., Metaxatos, P., & King, M. (2002). Effect of computer-assisted scheduling and dispatching systems on paratransit service quality. *Transportation research record*, 1791(1), 51-58.
- Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., ... & Moher, D. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *International journal of surgery*, 88, 105906.
- Papanikolaou, A., Basbas, S., Mintsis, G., & Taxiltaris, C. (2017). A methodological framework for assessing the success of Demand Responsive Transport (DRT) services. *Transportation Research Procedia*, 24, 393-400.
- Park, J., & Chowdhury, S. (2022). Towards an enabled journey: barriers encountered by public transport riders with disabilities for the whole journey chain. *Transport Reviews*, 42(2), 181-203.
- Partridge, E., Murphy, C., Faust, R., Karner, K., Sethi, S., & Kaufman, M. (2020). *Mobility on Demand (MOD) Business Models Synthesis Report* (No. FHWA-JPO-20-798). United States. Department of Transportation. Federal Highway Administration.
- Pandey, V., Monteil, J., Gambella, C., & Simonetto, A. (2019). On the needs for MaaS platforms to handle competition in ridesharing mobility. *Transportation Research Part C: Emerging Technologies*, 108, 269-288.
- Patel, R. K., Etmiani-Ghasrodashti, R., Kermanshachi, S., Rosenberger, J. M., & Foss, A. (2022). Mobility-on-demand (MOD) Projects: A study of the best practices adopted in the United States. *Transportation Research Interdisciplinary Perspectives*, 14, 100601.
- Pavone, M., Smith, S. L., Frazzoli, E., & Rus, D. (2012). Robotic load balancing for mobility-on-demand systems. *The International Journal of Robotics Research*, 31(7), 839-854.

- Périver, N., Hssaine, C., Samaranayake, S., & Banerjee, S. (2021). Real-time approximate routing for smart transit systems. *Proceedings of the ACM on Measurement and Analysis of Computing Systems*, 5(2), 1-30.
- Phun, V. K., & Yai, T. (2016). State of the art of paratransit literatures in Asian developing countries. *Asian Transport Studies*, 4(1), 57-77.
- Pi M, Yeon H, Son H, Jang Y (2021) Visual cause analytics for traffic congestion. *IEEE Transactions on Visualization and Computer Graphics* 27(3):2186–2201.
- Pillac V, Gendreau M, Guéret C, Medaglia AL (2013) A review of dynamic vehicle routing problems. *European Journal of Operational Research* 225(1):1–11.
- Raman, M., Schweiger, C., Shammout, K., & Williams, D. (2003). *Guidance for Developing and Deploying Real-time*
- Riggs, W., & Pande, A. (2022). On-demand microtransit and paratransit service using autonomous vehicles: Gaps and opportunities in accessibility policy. *Transport Policy*, 127, 171-178.
- Rizos, A. C. (2010). *Implementation of advanced transit traveler information systems in the United States and Canada: practice and prospects* (Doctoral dissertation, Massachusetts Institute of Technology).
- Rossetti, M. D., & Turitto, T. (1998). Comparing static and dynamic threshold-based control strategies. *Transportation Research Part A: Policy and Practice*, 32(8), 607-620.
- Rossetti, T., Broaddus, A., Ruhl, M., & Daziano, R. (2023). Commuter preferences for a first-mile/last-mile microtransit service in the United States. *Transportation research part A: policy and practice*, 167, 103549.
- Round, A., & Cervero, R. (1996). *Future ride: Adapting new technologies to paratransit in the United States*. SAE International (2018, October 1). *Definitions for Terms Related to Shared Mobility and Enabling Technologies*. <https://www.sae.org/>. Retrieved September 17, 2023, from <https://www.sae.org/publications/technical-papers/content/wp-0010/>
- Said, M., Zajdela, E. R., & Stathopoulos, A. (2022). Accelerating adoption of disruptive technologies: impact of COVID-19 on intentions to use on-demand autonomous vehicle mobility services. *Transportation Research Record*, 03611981221099276.
- Shaheen, S., & Cohen, A. (2019). Shared ride services in North America: definitions, impacts, and the future of pooling. *Transport reviews*, 39(4), 427-442.
- Stanley, J., Stanley, J., & Hansen, R. (2023). *How great cities happen: Integrating people, land use and transport*. Edward Elgar Publishing.
- Sayarshad, H. R., & Chow, J. Y. (2017). Non-myopic relocation of idle mobility-on-demand vehicles as a dynamic location-allocation-queueing problem. *Transportation Research Part E: Logistics and Transportation Review*, 106, 60–77.
- Schlosser, R. W., Wendt, O., Bhavnani, S., & Nail-Chiwetalu, B. (2006). Use of information-seeking strategies for developing systematic reviews and engaging in evidence-based practice: the application of

- traditional and comprehensive Pearl Growing. A review. *International Journal of Language & Communication Disorders*, 41(5), 567-582.
- Schweiger, C. L. (2011). Use and deployment of mobile device technology for real-time transit information (Vol. 91). Transportation Research Board
- Schrank D, Eisele B, Lomax T (2019) 2019 urban mobility report. Texas A&M Transportation Institute. The Texas A&M University System.
- Shaheen, S., & Chan, N. (2016). Mobility and the sharing economy: Potential to facilitate the first-and last-mile public transit connections. *Built Environment*, 42(4), 573–588.
- Sheffi, Y. (2015). Preparing for disruptions through early detection. *MIT Sloan Manage. Rev.* 57, 30–42.
- Shaheen, S., Cohen, A., Yelchuru, B., Sarkhili, S., & Hamilton, B. A. (2017). Mobility on demand operational concept report.
- Simonetto, A., Monteil, J., & Gambella, C. (2019). Real-time city-scale ridesharing via linear assignment problems. *Transportation Research Part C: Emerging Technologies*, 101, 208-232.
- Siuhi, S., & Mwakalonge, J. (2016). Opportunities and challenges of smart mobile applications in transportation. *Journal of Traffic and Transportation Engineering (English edition)*, 3(6), 582-592. Chicago
- Skobelev, P. (2015). Multi-agent systems for real-time adaptive resource management. In *Industrial Agents* (pp. 207–229). Morgan Kaufman
- Sonja Heikkilä, “Mobility as a Service – A Proposal for Action for the Public Administration, Case Helsinki,” Thesis submitted for examination for the degree of Master of Science in Technology, Aalto University, School of Engineering, April 28, 2014, [https://aaltodoc.aalto.fi/bitstream/handle/123456789/13133/master\\_Heikkil%20\\_Sonja\\_2014.pdf?sequence=1](https://aaltodoc.aalto.fi/bitstream/handle/123456789/13133/master_Heikkil%20_Sonja_2014.pdf?sequence=1)
- Spieser, K., Treleaven, K., Zhang, R., Frazzoli, E., Morton, D., & Pavone, M. (2014). Toward a systematic approach to the design and evaluation of automated mobility-on-demand systems: A case study in Singapore. *Road vehicle automation*, 229-245.
- Stone, J. R., Nalevanko, A. M., & Gilbert, G. (1994). Computer dispatch and scheduling for paratransit: an application of advanced public transportation systems. *Transportation Quarterly*, 48(2).
- Sumalee, A., & Ho, H. W. (2018). Smarter and more connected: Future intelligent transportation system. *Iatss Research*, 42(2), 67-71.
- Talley, W. K. (2013). Maritime transportation research: topics and methodologies. *Maritime Policy & Management*, 40(7), 709-725.
- TCRP Synthesis 63: “On-Board and Intercept Transit Survey Techniques, : 2016, <http://www.trb.org/Publications/Blurbs/156542.aspx>

- Thatcher, R., Gaffney, J. K., & Dynatrend, E. G. (1991). *ADA paratransit handbook: Implementing the complementary paratransit service requirements of the Americans with Disabilities Act of 1990* (No. UMTA-MA-06-0206-91-1). United States. Urban Mass Transportation Administration.
- The Washington D.C. Story*. TransitCenter Equity Dashboard. <https://dashboard.transitcenter.org/story/dc>
- Tsao, M., Milojevic, D., Ruch, C., Salazar, M., Frazzoli, E., and Pavone, M. (2019). Model predictive control of ridesharing autonomous mobility-on-demand systems. In 2019 International Conference on Robotics and Automation (ICRA), pages 6665–6671. IEEE.
- U.S. Government Accountability Office (2012). Report to the Committee on Banking, Housing, and Urban Affairs, U.S. Senate, Nov. 2012. <https://www.gao.gov/assets/660/650079.pdf>.
- U.S. DEPARTMENT OF TRANSPORTATION (2016, July 5). *Mobility on Demand (MOD) Sandbox Program / FTA*. Federal Transit Administration (FTA). Retrieved September 17, 2023, from <https://www.transit.dot.gov/funding/applying/notices-funding/mobility-demand-mod-sandbox-program>
- Volinski, J. (2019). Microtransit or public demand–response transit services: state of the practice (No. Project J-7, Topic SB-30).
- Wang, Y., Shen, Q., Ashour, L. A., & Dannenberg, A. L. (2022). Ensuring equitable transportation for the disadvantaged: Paratransit usage by persons with disabilities during the COVID-19 pandemic. *Transportation Research Part A: Policy and Practice*, 159, 84-95.
- Wasserman, J. L., Rios, N., King, H., Siddiq, F., Bressette, B., & Taylor, B. D. (2022). Transit (ory) Finance: The Past, Present, and Future Fiscal Effects of COVID-19 on Public Transit in Southern California.
- Webb, J. (2019). The future of transport: Literature review and overview. *Economic Analysis and Policy*, 61, 1-6.
- Wee, B. V., & Banister, D. (2016). How to write a literature review paper? *Transport Reviews*, 36(2), 278-288.
- Weinreich, D. P., Reeves, S. M., Sakalker, A., & Hamidi, S. (2020). Transit in flex: Examining service fragmentation of app-based, on-demand transit services in Texas. *Transportation Research Interdisciplinary Perspectives*, 5, 100060.
- Westervelt, M., Huang, E., Schank, J., Borgman, N., Fuhrer, T., Peppard, C., & Narula-Woods, R. (2018). UpRouted: Exploring Microtransit in the United States
- Wilbur, M., Ayman, A., Sivagnanam, A., Ouyang, A., Poon, V., Kabir, R., ... & Dubey, A. (2023). Impact of COVID-19 on public transit accessibility and ridership. *Transportation Research Record*, 2677(4), 531-546
- Wilbur, M., Coursey, M., Koirala, P., Al-Quran, Z., Pugliese, P., & Dubey, A. (2023, May). Mobility-On-Demand Transportation: A System for Microtransit and Paratransit Operations. In *Proceedings of the ACM/IEEE 14th International Conference on Cyber-Physical Systems (with CPS-IoT Week 2023)* (pp. 260-261).

- Wolpert, S., & Reuter, C. (2012). Status quo of city logistics in scientific literature: systematic review. *Transportation Research Record*, 2269(1), 110-116.
- Wong, Y. Z., Hensher, D. A., & Mulley, C. (2020). Mobility as a service (MaaS): Charting a future context. *Transportation Research Part A: Policy and Practice*, 131, 5-19.
- Yan, X., Zhao, X., Han, Y., Van Hentenryck, P., and Dillahunt, T. (2019). Mobility-on-demand versus fixed-route transit systems: an evaluation of traveler preferences in low-income communities. ArXiv Preprint ArXiv:1901.07607.
- Yigitcanlar, T., Kamruzzaman, M., Foth, M., Sabatini-Marques, J., Da Costa, E., & Ioppolo, G. (2019). Can cities become smart without being sustainable? A systematic review of the literature. *Sustainable Cities and Society*, 45, 348-365.
- Zhang, X., Yan, M., Xie, B., Yang, H., & Ma, H. (2021). An automatic real-time bus schedule redesign method based on bus arrival time prediction. *Advanced Engineering Informatics*, 48, 101295.
- [Youtube]. (2023, June 28). *State-Level Technology Decision-Making* [Video]. <https://N-Catt.org/>. <https://n-catt.org/resources/state-level-technology-decision-making/>
- Yuan, J., Zheng, Y., Zhang, L., Xie, X., Sun, G., 2011. Where to find my next passenger? In: Proceedings of the 13th International Conference on Ubiquitous Computing. ACM New York, NY, USA, pp. 109–118.
- Zupic, I., & Cater, T. (2015). Bibliometric methods in management and organization. *Organizational Research Methods*, 18(3), 429–472.
- Optimizing mass transit response*. (2021, May 28). <https://advisory.kpmg.us/articles/2019/accelerating-mobility.html>
- Sonja Heikkilä, “Mobility as a Service – A Proposal for Action for the Public Administration, Case Helsinki,” Thesis submitted for examination for the degree of Master of Science in Technology, Aalto University, School of Engineering, April 28, 2014, [https://aaltodoc.aalto.fi/bitstream/handle/123456789/13133/master\\_Heikkil%20\\_Sonja\\_2014.pdf?sequence=1](https://aaltodoc.aalto.fi/bitstream/handle/123456789/13133/master_Heikkil%20_Sonja_2014.pdf?sequence=1)

# **3 On-Demand Transit (ODT): An Exploratory Case Study of Washington DC's Efforts to Improve Service Outcomes**

## **Abstract**

The rapid advancement in digital technologies has given rise to On-Demand Transit (ODT) systems that aim to provide accessible transportation. These systems have been widely embraced in the Washington, D.C., area, with the D.C. Neighborhood Connect leading the way. This on-demand shared-ride shuttle service provides first-mile connections in selected service zones in the City's Northern, Southern, and Ward 8 (East of the River) parts at varying service levels. ODT systems offer numerous benefits, including affordable and accessible transit that improves connections to jobs and new opportunities in communities where fixed-route bus transit may be insufficient. However, implementing ODT services is challenging and requires clear performance outcomes and policies. The benefits of ODT can only be realized if key performance outcomes such as on-time performance and ridership operating costs are aligned with the design and needs of the communities and not just a single element of performance. This exploratory case study collected survey and expert interview data between November 2021 and May 2022 on Washington, DC's Neighborhood Connect on-demand shared-ride shuttle service. Results show that ODT performance outcomes vary across the region due to travel patterns, operating conditions, policies, and social and economic attributes of the service zones in the District of Columbia. ODT services provide vital, accessible transit coverage in underserved communities, with the shortest wait time and high on-time performance. This research contributes to the emerging academic literature on ODT services by using a case study to explore performance outcomes regarding ridership, on-time performance, and operating costs. This study will also help inform the policymaking, service planning processes, and the implementation of ODT services.

### 3.1 Introduction

This research advances an exploratory case study of the Washington DC Neighborhood Connect on-demand transit (ODT service) and related planning efforts to improve performance and service outcomes. Transit agencies can evaluate ODT performance more objectively by analyzing trends over the years or comparing modes or peer systems. This type of analysis can also help planners identify and prioritize areas that require management action (Gan et al., 2011). This study aims to explore the performance of the Neighborhood Connect service in Washington, D.C., to improve ODT service planning and decision-making. The study examines and measures the performance of ODT, primarily focusing on service effectiveness based on ridership, operating costs, and on-time performance.

It is important to consider more than just basic measures like unlinked passenger trips or operational costs per hour when evaluating the performance of a service. According to Hansen et al. (2021), the functional structure of on-demand transit (ODT), which includes microtransit service, is still new and evolving. This means there are no established performance measures or service standards for transit agencies to use when evaluating potential new ODT service zones or assessing existing ones. This research investigates ODT performance measures to understand how well ODT meets the needs of individual riders, how well the service performs in meeting service demand, and what the system's local impacts are. It is important to establish an effective ODT system that prioritizes the needs of riders and evaluates its performance in a customer-centric way (Administration, (2020).

As ODT technologies continue to gain popularity, they are increasingly seen as a potential solution to the issues associated with public transit (Ghimire et al., 2024). However, more literature is needed on ODT, and there is a significant lack of understanding regarding planning and

implementation practices, operational challenges, and compliance with federal and state requirements that transit agencies face in implementing service (Bardaka et al., 2023). The lack of operating data and best-practice standards under existing public-private partnership models is also challenging (Curtis et al., 2019; Westervelt et al., 2017). The lack of data on ODT reliability, accessibility, cost sustainability, and the safety of drivers and riders remains a leading concern (National Academies of Sciences, 2021).

This study contributes to the growing literature on app-based ODT services by exploring ODT performance outcomes for on-demand transit, which has significant implications for public transportation (Administration, 2020). The performance of ODT services is evaluated based on organizational objectives and constraints. ODT operational strategies can include point-to-point service within a specific area, first-last mile service, which allows riders to be picked up at flexible stops within a particular area, and hub-and-spoke service that combines features of both. These strategies can be helpful under uncertain future conditions. By studying ODT service performance outcomes, transit agencies and policymakers can better understand the implications for the future of service delivery. Transit planners can develop strategies and incentives to improve services based on what matters most to riders and align with their goals and priorities (Administration, 2020). Transit agencies and practitioners can explore software, vehicles, drivers, and operational and maintenance factors to better plan (Ghimire et al., 2024; Partridge et al., 2020).

## **3.2 Background Literature**

This section focuses on previous studies on ODT, including definitions, service types, model descriptions, challenges and drawbacks, the Dial-a-ride problem, ODT adoption approaches, mode performance measures, and potential benefits of ODT.

On-demand transit (ODT) services provided through mobile applications are an area of increasing interest and research. This study contributes to the growing literature in this field. ODT has emerged as a critical component in delivering demand-responsive services, gaining popularity as people now expect better accessibility and flexible transit options (Bürstlein et al., 2021). ODT provides flexible services tailored to user demands, with customizable origin and destination routing and pick-up timing (Bürstlein et al., 2021). Public transit agencies are adapting new service delivery models like ODT, including on-demand paratransit, on-demand shuttle, e-hailing, and microtransit. Most ODT services are designed to address real-time travel demands by adjusting routes and schedules dynamically for point-to-point transit, using sophisticated algorithms to optimize route, routing, and service delivery, making it more efficient, flexible, and dynamic for users (Sanaullah et al., 2021; Mulley & Nelson, 2009). In this study, ODT has been used interchangeably to refer to various forms of same-day and flexible-route service offerings for the public that are not traditional fixed-route, fixed-schedule transit services. In broad terms, ODT is a subset of paratransit, and microtransit is a subset of ODT. As the demand for ODT services increases, requiring additional services and resources, there is a need to improve performance and create or establish clear service objectives to meet riders' expectations.

Several studies suggest that a centralized, demand-responsive shared ride service operated through ODT could benefit riders and transit providers. For example, Atkinson et al. (2013) noted that due to the cost of providing new capacity, transit agencies are starting to focus on building operational capacities by enhancing opportunities to maximize the efficiency of transportation systems. Studies indicate that transit agencies have begun incorporating ODT into their network, using small vehicles with dynamic routing and scheduling, providing riders greater convenience in requesting, tracking, and paying for trips. Examples of these services include alternative demand-responsive services such as on-demand rides, microtransit, and first-mile/last-mile that may be

delivered through partnerships with ride-hailing providers and taxis to provide on-demand and same-day services to improve transit outcomes (Ashour & Shen, 2022; Grabar, 2016; Brustein, 2016).

Adopting ODT promises to address transit agencies' issues with fairness, affordability, accessibility, and connection (Feigon & Murphy, 2016; Weinreich et al., 2020; Mouter, 2021). By offering more predictable pricing, public subsidies, and customized services that close the gaps in the fixed-route transit system, public transit agencies perceive the potential to leverage ODT services to manage paratransit demand and capacity limitations (Weinreich et al., 2020; Rayle et al., 2014). The availability of new technology has produced new market prospects for on-demand transport across the county, resulting in a steady evolution of the demand-responsive transit sector. ODT can be a less expensive option to serve places that fixed-route choices cannot economically serve compared to fixed-route and ADA paratransit services.

ODT app-based, dynamic ridesharing is a centralized framework that uses real-time vehicle routing to pool multiple trips with similar origins, destinations, and departure times in the exact vehicle. The system can find the nearest idle vehicle and the fastest travel and arrival time to a particular destination (Wang et al., 2019). ODT is an evolving concept that leverages smartphones to enable the real-time matching of consumers and service providers to their destinations (Shaheen & Chan, 2016; Qiu et al., 2015). Volinski (2019) suggests that transit agencies can enhance the quality and effectiveness of their service delivery.

## **Defining ODT**

With many new terms describing on-demand transit services, a definition for shared-used on-demand public transit services is warranted.<sup>4</sup> ODT is a form of demand-responsive shared-use public

---

<sup>4</sup> Demand Response Transit/Microtransit: A Guide for Implementing Flexible Transportation Services.  
[\\*Arlington County Guide for Flexible Transit reduced2019.pdf \(arlingtontransit.com\)](https://www.arlingtontransit.com/files/2019/04/Arlington-County-Guide-for-Flexible-Transit-reduced2019.pdf)

transit service such as resourcing, ridesharing, and on-demand paratransit services that allow riders to request rides on-demand or in advance to book rides to their destinations (Shaheen et al., 2018; Westervelt et al., 2018; Bardaka et al., 2023). ODT utilizes dynamic routing to provide flexible shuttle-like services that offer comparable transit services for multiple origins and destinations on a shared trips framework (Hazan et al., 2019; Westervelt et al., 2018; Bardaka et al., 2023). ODT is a public transit service that uses technology to enable multi-passenger rides. It operates like private rideshare services with the help of a mobile or cloud computing infrastructure framework. ODT services allow passengers to plan trips, hail rides, pay fares, and track point-to-point services via smart devices or app-based platforms, facilitating better modal choice decisions. With ODT, riders can book and pay for their trips online using smartphone apps, personal computers, or mobile devices connected to the internet (Hazan et al., 2019; Wang et al., 2019). Table 10 below summarizes key features and terms associated with ODT.

**Table 10 Summary of Key Terminology Associated with ODT**

Key Terminology	Description
Transportation Network Company (TNC)/ Mobility Service Provider (MSP)	A company that provides transportation services using an Online-enabled platform to connect passengers with drivers operating their personal vehicles (California Public Utilities Commission, 2013).
Ridesourcing/Ridesharing/ Ride(e)-hailing	Adding passengers to a private trip where the driver and passengers share a destination. The arrangement provides additional transportation options for riders while allowing drivers to fill empty vehicle seats (Conway et al., 2018).
Mobility on Demand (MOD)	An innovative, user-focused approach that leverages emerging mobility services, integrated transit networks and operations, real-time data, connected travelers, and cooperative Intelligent Transportation Systems (ITS) to allow for a more traveler-centric, transportation system-of-systems approach, providing improved mobility options to all travelers and users of the system efficiently and safely (U. S. Department of Transportation).
Ride-splitting	A type of ride-sourcing that allows customers requesting a ride for one or two passengers to be paired in real-time with others traveling along a similar route (TCRP Research Report 188).

Shared Mobility	Transportation services and resources that are shared among users, either concurrently or one after another. This includes public transit; taxis and limos; bikesharing; carsharing (round-trip, one-way, and peer-to-peer); ridesharing (i.e. non-commercial services like carpooling and vanpooling); ridesourcing; ride-splitting; scooter sharing (now often grouped with bikesharing under the heading of “micromobility”); shuttle services and “microtransit”; jitneys and dollar vans; and more (Shared-Use Mobility Center).
-----------------	---

Source: KHF (2019). *Demand Response Transit/Microtransit: A Guide for Implementing Flexible Transportation Services*. [Arlington County Guide for Flexible Transit\\_reduced2019.pdf \(arlingtontransit.com\)](https://www.arlingtontransit.com/sites/default/files/2019-09/Arlington_County_Guide_for_Flexible_Transit_reduced2019.pdf)

## ODT Service Types

Numerous ODT schemes have been introduced, with various models used to examine and define ODT services. These schemes are classified into multiple models or service types operated by public transit agencies, including ride-sourcing, shared ride, and ride-hailing (Rayle et al., 2016; Clewlow & Mishra, 2017). These services differ from carpooling or ridesharing services, which are co-ops for which users pay a membership fee to drive themselves (Koffman, 2004; Rayle et al., 2016; Clewlow & Mishra, 2017). The definitions of these different types of ODT services are summarized in Table 11 (Potts et al., 2010).

**Table 11. Types of On-demand Transit (ODT) Models**

Route Deviation	Route deviation is a transportation service where vehicles follow a pre-established route, with or without specific stops. Nevertheless, the service provider may modify the path to cater to demand-responsive requests within a particular zone surrounding the route. The zone’s scope may be strictly defined or flexible based on the needs. The scope of this area may either be fixed or adjustable.
Request Stops	Request stops are designated along a fixed route but can accommodate additional stops upon passenger request.
Zone Routes	Zone route refers to vehicles traveling along a corridor with established departure and arrival times in a demand-responsive mode.
Flexible Route Segments	Flexible-route segments have a fixed route and schedule but can switch to an on-demand service for a limited part of the trip.
Point Deviation	<i>Point deviation</i> is a transportation service that offers on-demand travel within a specific area. Unlike traditional services, it serves several stops without adhering to a predetermined route. This flexibility is especially advantageous when there are limited trip origins yet plenty of viable destinations within a specific area. It is also ideal in situations with ample trip origins but limited viable destinations.

Demand-Responsive Connector	Demand-responsive vehicles operate within a designated zone, connecting with fixed-route networks at scheduled transfer points.
-----------------------------	---

## ODT Modal Description

Unlike traditional paratransit, ODT is available to anyone in the defined service area (zone), which requires riders to meet eligibility requirements and trips to be scheduled in advance.<sup>5</sup> A public or private operator can operate ODT to provide on-demand services based on dial-a-ride, app-based, or hybrid models that provide origin and destination transit services such as door-to-door, curb-to-curb, and curb-to-hub. Various technologies are integrated to provide ODT services, such as software for trip requests, trip scheduling, dispatching, routing, etc., and trip booking requirements such as on-demand, day-of service, or booking, user eligibility (everyone or restricted), zone type (large, small), span of service, payment requirement, etc. (Kaufman et al., 2016; Patel et al., 2022; Weinreich et al., 2020; Koffman, 2004; Wilbur et al., 2023).

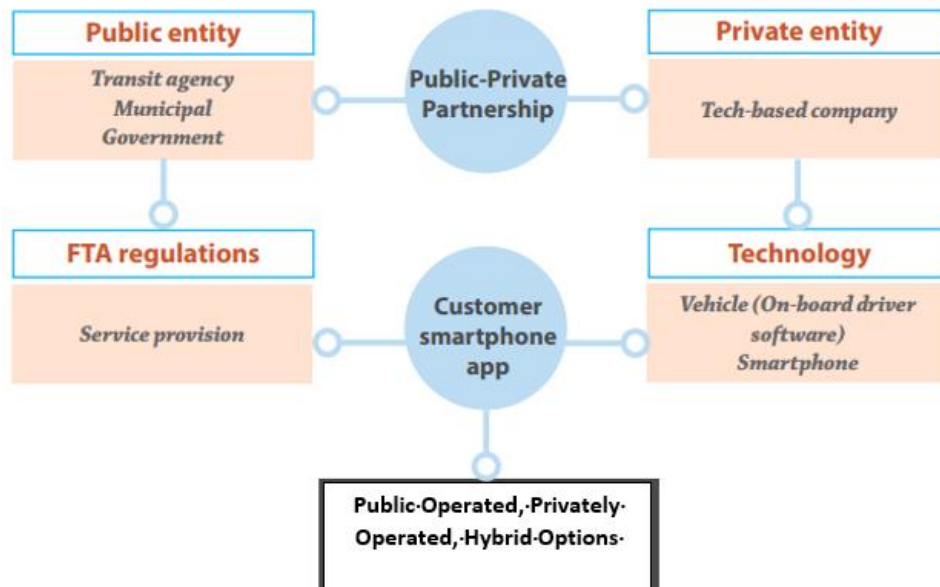
## Service Delivery Model

Municipalities and transit agencies offer ODT, including in-house publicly-operated services and privately-operated models that may include tech-based mobility providers supplying the drivers and operating the service. However, third-party companies typically operate most services (Westervelt et al., 2018). ODT services are like ride-sharing services offered by TNCs, such as UberPool, LyftLine, and the Bandwagon app, but are heavily subsidized like other forms of public transportation. Like microtransit, these services group many riders and use predetermined pickup and drop-off locations, community vehicles, and drivers closer to ridesplitting (Shaheen & Chan, 2016). UberHOP operates in some cities and is an on-demand ridesplitting service for peak-period

---

<sup>5</sup> BERGAL, J. (2022, November 10). *On-Demand Microtransit: A Rural Solution to Public Transit?* Retrieved October 15, 2023, from <https://www.planning.org/planning/2022/fall/on-demand-microtransit-a-rural-solution-to-public-transit/>

travel. At the same time, the Bandwagon app is a platform for splitting the fare. It combines ridesplitting with e-Hail to facilitate taxi splitting by matching riders going in a similar direction in taxis and provides (Shaheen & Chan, 2016). According to Martinez and Viegas (2017), there is an emerging paradigm for multiple mobility operators and technology providers working together to deliver ODT service. The delivery of ODT services is based on an integrated approach that requires collaboration between a public entity, private mobility provider, federal oversight and compliance, and technology used in service provision.<sup>6</sup> Figure 3 shows a sample of ODT service delivery models.



Source: Demand Response Transit/Microtransit: A Guide to Implementing Flexible Transportation Services.

Figure 3 A Typical ODT Service Delivery Model

According to Weinreich et al. (2021), one of the key benefits of ODT is its flexibility to fill gaps in areas where traditional public transit is not available or practical. Municipalities and transit agencies are working to optimize service operations management, match trips with similar origins

<sup>6</sup> KFH (2019, September 24). *Demand Response Transit/Microtransit: A Guide for Implementing Flexible Transportation Services*. Arlingtontransit.com. Retrieved June 21, 2022, from [https://www.arlingtontransit.com/sites/art/assets/File/Arlington\\_County\\_Guide\\_for\\_Flexible\\_Transit\\_reduced2019.pdf](https://www.arlingtontransit.com/sites/art/assets/File/Arlington_County_Guide_for_Flexible_Transit_reduced2019.pdf)

and destinations, and minimize operating costs for transit agencies (Wilbur et al. (2023). The geographical service area is an essential concept in ODT implementation and is based on specific zones or routes within a particular area where rides can be requested (Weinreich et al., 2020; Errico et al., 2013; Koffman, 2004).

In the National Capital Region, there is a growing emphasis on implementing demand-responsive transportation services to provide flexible travel choices and customer-centric transportation options for underserved communities.<sup>7</sup> However, ODT service concepts are still evolving, and there is no one-size-fits-all model to address the lack of access to public transit, which is a significant challenge in many cities. Issues regarding the equity of services still need to be managed (Shaheen & Chan, 2016).

## **ODT Challenge with High Operating Costs**

Despite its popularity, potential impacts, and opportunities, as ODT services expand, some challenges remain. These include cost burdens for delivering ODT services, service performance issues, monitoring public-private partnerships, and public policy such as fair labor practices (Weinreich et al., 2021; Shaheen & Chan, 2016). According to Chow and Sayarshad (2016), deficient performance can be observed in some cases. Challenges that have hindered the development of fixed route services are re-surfacing as transit agencies adopt ODT systems (Weinreich et al., 2021). For example, in 2022, Jersey City offered ODT service at \$2 per trip, delivered through a contract with Via, a private mobility provider valued at about \$7.5 million

---

<sup>7</sup> The National Capital Region Transportation Planning Board (TPB) is (2023, November 1). *STATE OF PUBLIC TRANSPORTATION 2022 REPORT*. [www.Mwcog.org](https://www.mwcog.org). Retrieved December 15, 2023, from [https://www.mwcog.org/assets/1/6/2022\\_State\\_of\\_Public\\_Transportation\\_Report\\_FINAL.pdf](https://www.mwcog.org/assets/1/6/2022_State_of_Public_Transportation_Report_FINAL.pdf)

annually for operating the service.<sup>8</sup> In Los Angeles Metro, the on-demand transit pilot program quickly faced challenges as it failed to attract high ridership for a microtransit ride that cost passengers only \$1. Each trip has a subsidy of \$42,<sup>9</sup> amounting to about \$31 million over three years.<sup>10</sup>

An efficient dispatching and routing policy can help reduce operating costs and customer ride time. The Dial-a-Ride Problem (DARP) method has been proposed to address static and dynamic problems, where decisions are made over time and demand is unknown in advance. DARP has been utilized to explain the cost challenges associated with demand response transit systems that face an uncertain financial future. Understanding the Dial-A-Ride Problem (DARP) can help define these challenges and guide ODT policies to maximize its adoption and benefits.

### **Dial-A-Ride Problem (DARP)**

Demand response transit has been facing challenges since its inception in allocating and optimizing resources while catering to the transit needs of riders. This issue of effectively scheduling trips and assigning vehicles to minimize costs and maintain reliability is known as the Dial-A-Ride Problem (DARP). DARP is a complex problem that involves scheduling and assigning vehicles to dynamic trip requests without prior knowledge of traffic conditions, available capacity, and variations in trip requests, such as pick-up and drop-off times at any given time of the day. As customer trips are booked, vehicle routes can become increasingly inefficient, leaving room for

---

<sup>8</sup> KFH (2019, September 24). *Demand Response Transit/Microtransit: A Guide for Implementing Flexible Transportation Services*. Arlingtontransit.com. Retrieved June 21, 2022, from

[https://www.arlingtontransit.com/sites/art/assets/File/Arlington\\_County\\_Guide\\_for\\_Flexible\\_Transit\\_reduced2019.pdf](https://www.arlingtontransit.com/sites/art/assets/File/Arlington_County_Guide_for_Flexible_Transit_reduced2019.pdf)

<sup>9</sup> Zipper, D. (2023, December 19). *On-Demand Microtransit Can't Escape This Big Problem*. Bloomberg.com. Retrieved December 29, 2023, from

[https://www.arlingtontransit.com/sites/art/assets/File/Arlington\\_County\\_Guide\\_for\\_Flexible\\_Transit\\_reduced2019.pdf](https://www.arlingtontransit.com/sites/art/assets/File/Arlington_County_Guide_for_Flexible_Transit_reduced2019.pdf)

<sup>10</sup> URANGA, R. (2023, September 14). *The \$1 ride that costs Metro \$43. Why some want to keep it going*. Latimes.com. Retrieved December 29, 2023, from <https://www.latimes.com/california/story/2023-09-14/the-1-ride-that-costs-metro-43-is-this-pilot-van-program-worth-the-costs>

improvement once the booking process stops at the end of each day (Gupta et al., 2010; Cordeau & Laporte, 2007). ODT services such as microtransit, as described by Hansen et al. (2021), offer a higher level of service than traditional demand response. This is due to its ability to respond to real-time trip requests and provide better connectivity to fixed-route systems.

Transit agencies face many challenges, such as increasing demand, high operating costs, outdated technology systems, and poor quality of service for paratransit users (Kaufman et al., 2016; Koffman, 2004). ODT can help solve these by optimizing real-time scheduling and routing, which allows for adjusting and balancing service demand and supply while maximizing service quality and efficiency (Gupta et al., 2010). However, as municipalities and transit agencies attempt to adjust to the shift to the new and changing mobility landscape, there is a need for planning and policymakers to understand their needs and to implement the right on-demand technology solutions (Sisson, 2018, January 9).

The alignment of ODT service goals, design, and performance outcomes is essential. ODT services must be flexible and cost-effective to solve challenges faced by traditional public transit services, such as ridership declines, high costs, inefficiencies, and lack of mobility options for underserved communities (Erhardt et al., 2022). This allows transit agencies to provide more equitable transit options for riders without significant infrastructure investments (Atkinson et al., 2013; Westervelt et al., 2018). However, whether ODT services are designed or oriented to address these challenges has yet to be discussed in the literature by researchers. Establishing performance criteria to determine how ODT performs and measuring outcomes are essential. Defining key performance measures is a crucial step in planning and selecting the future of the service and allowing transit managers and policymakers to track and assess ODT performance against planning and policy objectives.

## **Benefits of ODT Technologies**

Dynamic ride-sharing technologies can enable transit agencies to shift their operating model to implement ODT to help manage trip demand and supply, reduce operating costs, and improve travel time (Čertický et al., 2014; Smith et al., 2018). Wang et al. (2019) argue that dynamic ridesharing can mitigate the dial-a-ride or scheduling problem to provide demand-responsive transit services. For instance, dynamic ridesharing algorithms can reduce average waiting time, vehicle miles traveled, and idle and empty vehicles. Across the country, adopting ODT presents a new mode of public transit to address multiple challenges, including service planning gaps such as transit equity and sustainability and operational issues such as operating costs, ridership, and on-time performance (Feigon & Murphy, 2016; Weinreich et al., 2020; Mouter, 2021). Due to its flexibility and use of algorithms, ODT services can improve transit outcomes and performance in terms of ridership, operating costs, and on-time performance, including waiting time reduction (Shaheen & Chan, 2016; Alsaleh & Farooq, 2023). ODT services have emerged as a critical component in delivering demand-responsive services, and their popularity has increased in the last decade. The emergence of TNCs (like Uber and Lyft) and private mobility providers (like RideCo and Via) have paved the way for new technology-based transportation services. These on-demand services connect riders and drivers and aim to serve public transit riders by providing more predictable pricing, public subsidies, and tailored services that fill the gaps in the fixed-route transit system (Weinreich et al., 2020; Rayle et al., 2014).

ODT is a new transportation mode and is still being researched. Preliminary studies have identified equity as a concern for this emerging app-based service (Weinreich et al., 2020; Rogers, 2015).

This research focuses on ODT services, including on-demand paratransit, microtransit, first and last-mile transit, and other rideshare services that are easy to use and offer flexibility of choice, convenience, and reliability to help improve customer service experience. Previous studies have looked at various aspects of ODT, including the real-time operating policy of ridesharing as a feeder for first and last-mile solutions in coordinating vehicle dispatching and routing to service existing public transportation networks (Ma, 2017). ODT can substitute public transit due to the higher comfort, greater flexibility, and convenience compared to fixed-route public transit services (Alonso-González et al., 2018). Depending on the transit needs, several factors can influence the service design for microtransit, and the types of service implemented.

The various aspects of ODT services include first/last mile service that connects users to key points at the start and end of their journey. Ridesharing allows private vehicles and drivers to provide point-to-point transportation with the ability to accept or add passengers to an existing trip with a similar destination. Traditional forms of ridesharing include carpooling and vanpooling (Westervelt et al., 2018). Ride-splitting allows customers requesting a ride for one or two passengers to be paired in real-time with others traveling along a similar route. Shared mobility integrates advanced technologies, including electronic and wireless communication systems, to provide alternative services to users, including public transit, taxis, and limos, bikesharing, carsharing (round-trip, one-way, and personal vehicle sharing), and ridesharing (carpooling, vanpooling) (Ho et al., 2018; Hall et al., 2018; Shaheen et al., 2017).

## **Performance-Based Planning for ODT**

Performance-based planning combines performance management and transportation planning principles to link transit performance evaluation and policy decisions.<sup>11</sup> Ellis and McCollom (2009) explain that performance measurement begins with setting clear goals and objectives for the service, followed by determining the measures and indicators that best capture the essential aspects of ODT service and operations. Transit agencies have measured their performance using metrics such as costs per traveler trip or mile, on-time performance (wait-time), and ridership based on average passengers/trips (Administration, 2020). However, these performance measures have not been studied in the ODT service context.

ODT services are still in their preliminary stages, meaning there are no established industry standards for measuring performance and productivity. There are only a few studies on the effectiveness of ODT services based on performance outcomes. As a result, the performance standards for ODT services are somewhere between conventional demand response and fixed routes. It is crucial to determine the performance outcomes that are most and least affected to help identify the design requirements for ODT services.

This research focuses on three widely used performance measures for evaluating the *efficiency* and *effectiveness* of public transit services – on-time performance, ridership, and operating costs (Fielding et al., 1985). These measures are widely used in the transit industry, and transit providers must report their monthly and annual performance data to the National Transit Database (NTD) (Ellis & McCollom, 2009). The aim is to encourage planners to use performance measures in the design and planning of ODT services to help increase ridership, reduce operating costs (i.e.,

---

<sup>11</sup> FDOT (2014, July 1). *Best Practices in Evaluating Transit Performance*. Fdot.gov/. Retrieved December 29, 2023, from <https://www.fdot.gov/docs/default-source/transit/pages/BestPracticesinEvaluatingTransitPerformanceFinalReport.pdf>

decrease the average cost per ride), and improve the system’s economic efficiency (Matherly, 1997; Pinto et al., P. V. (2021). This has important policy implications for how public funds are allocated and transit services are contracted to promote equity and inclusion (Matherly, 1997). Transit planning and policy regarding ODT should prioritize aligning performance measures with established performance goals. Table 13 provides the proposed evaluation hypotheses for three performance goals.

**Table 12 Proposed ODT Performance Measures Used**

<b>Performance Measure</b>	<b>Definition</b>	<b>Performance Goals</b>	<b>Evaluation Hypothesis</b>	<b>Performance Metric</b>
<b>Ridership</b>	Total or average daily trip counts per vehicle hour	Increase ridership	Ridership will increase because of the ODT service	Passenger trips per vehicle hour; Average daily trips; Count of unlinked trips or unique ODT users
<b>On-time performance</b>	On-time performance is the duration between requesting a trip and the vehicle's arrival.	Increase reliability; lower travel and wait times	Travel and delay times of users decrease because of the ODT service	Percentage of trips that arrived within their estimated arrival time; Reported travel times and wait times
<b>Operating costs</b>	Operating cost/passenger trips and operating cost/revenue mile	Increase cost-effectiveness	ODT cost per trip is lower than paratransit and fixed route	Operating cost per passenger trip

Evaluating the performance of ODT services from multiple perspectives based on a combined evaluation method is crucial (Zhang et al., 2016). Currently, the transit industry utilizes performance metrics such as customer satisfaction, reliability, time, and cost-effectiveness to measure outcomes (Administration, 2020). Reliable transportation services rely heavily on their ability to maintain an excellent on-time performance (OTP) record, as Guenther and Hamat (1988) noted. The wait time is the duration between the request for a ride and the arrival of the vehicle for pickup. Ride time refers to the duration of the ride. Measuring the timeliness of pickup and drop-off is important, which makes calculating the response time between trip requests and vehicle arrival crucial. A low OTP percentage indicates ineffective and unreliable services, leading to longer

waiting times. A shorter waiting time can encourage more people to ride buses. Providing reliable bus arrival times effectively reduces waiting time (Errico et al., 2013; Guenther & Hamat, 1988).

Ridership refers to the number of completed passenger trips. ODT, such as microtransit, prioritizes ridership as a fundamental goal. High ridership is in line with transit-oriented development, whereas low ridership may indicate a lack of accessibility, particularly in suburban areas. ODT services can be extended to low-density residential areas to increase overall ridership. Well-designed ODT services have the potential to generate higher ridership than traditional on-demand transportation services. At the agency level, evaluating ODT performance and determining success criteria can be based on the perceived importance of attributes while striving to enhance performance, optimize cost and efficiency, and maximize rider satisfaction. Transit effectiveness measures transit system riders' perspectives and often measures service utilization (ridership), service quality (reliability, accessibility), and service satisfaction (Fielding et al., 1985). Therefore, understanding how these technologies are adopted is critical in developing appropriate policy measures (Sweet & Scott, 2021).

The efficiency of ODT services can be measured by calculating the operating cost per passenger trip. Efficiency indicators describe the relationship between resource inputs and expected outputs, including overall operating cost efficiency. The operating cost per passenger trip is a combined measure considering operating cost and passenger trips per revenue hour. This measure determines the hourly operating cost productivity. However, when compared to fixed-route bus services, it is found that demand-responsive modes like ODT have significantly higher per-passenger trip costs (Ellis & McCollom, 2009). This study examines the operating cost per passenger trip, including operating cost per passenger trip and operating cost per revenue mile (operating cost/revenue miles), which measures the productivity of an ODT service. Operating costs also help

to determine customer affordability, which is a significant challenge to the widespread adoption and implementation of ODT services (Steiner et al., 2021). Low ridership on ODT often leads to concerns about operational costs, making cost a challenging measure of success for these services (Steiner et al., 2021).

Regardless of the ODT technology, there are limitations on how the performance of ODT services is measured and the extent to which the data informs ODT planning, service design, and operations. These new service models still require extensive research. Therefore, transit agencies and departments of transportation must understand the benefits and challenges of ODT solutions. This research explores the outcomes of ODT services to identify lessons learned and inform future policy and planning for ODT services, such as flexible routes and on-demand microtransit.

### **3.3 Research Questions**

This study aims to answer several research questions using survey and interview data. These questions include:

1. How does ODT improve transit outcomes?
2. What are the performance outcomes for DCNC service regarding ridership, on-time performance, and operating costs?
3. What are the technological features of on-demand transit services, and how do they impact the performance outcomes of such services?

### **3.4 Research Methods**

Chapters 1 and 2 discussed how operating costs pose a significant challenge for transit agencies. However, current methods that evaluate the benefits of ODT often overlook the impact it has on operating costs, as they focus solely on ridership. There is a need for information/data on

ODT performance. To better understand how DCNC performed based on the local jurisdictional staff perspectives.

DCNC was selected as a case study since D.C. is a regional and national leader in investing in public transit, including microtransit service concepts that use app-based, on-demand services. Compared to other jurisdictions in the Washington D.C. metropolitan area, the city has a well-regulated environment, allowing app-based on-demand services to flourish. Also, from a unified ordinance and policy perspective, DC operates as a single state, permitting it more control over exploring ODT. D.C. is centralized within a large metropolitan area and has one of the nation's best public transit systems. Living and working in the D.C. area allowed me to use my network to facilitate data collection, including data from a "state" agency where local governments have a relatively high degree of autonomy compared to their peers in other states, making data collection easier. Weinreich et al. (2020) apply the same rationale in their study of app-based, on-demand transit services in Texas.

To achieve my research goals, this study employed a mixed research method consisting of an online survey and semi-structured interviews. My objective was to examine the agency's approach toward ODT service planning and performance measures and to gain insight into transit professionals' perceptions and experiences regarding the evolution of ODT services. Therefore, a case study involving quantitative (survey) and qualitative (interview) investigations was deemed suitable. This approach was necessary to address the research questions adequately and collect and analyze data thoroughly (Kennedy et al., 2013).

This study used a survey to collect general information about performance outcomes and other ODT service attributes from transit professionals. However, to gain a more comprehensive understanding of ODT services, semi-structured interviews were conducted using an interview guide

to allow for contextual data and follow-up questions with each interviewee. I employed a scoping approach in collecting data, which involved informally seeking data and evidence from the department staff. O'Brien et al. (2016) describe scoping studies as a way to map evidence comprehensively and contextualize knowledge by identifying the current state of understanding, identifying the sorts of things we know and do not know, and then setting this within policy and practice contexts.

## **Data Collection**

Relevant data, such as documents and studies that were not publicly available, to identify the existing ODT services and zones in the Washington D.C. region. This included data on operational characteristics and perspectives of local transit providers on ODT adoption. Informal interview sessions with staff members of local agencies were conducted to gather ideas and feedback on ODT service development, planning, performance, and operational data. Data on the neighborhood zones, operating characteristics, and the perspectives of DCNC staff regarding their services were collected. This information is crucial in planning, designing, adopting, and operating the service, as Alsaleh and Farooq (2023) pointed out. This study shares similarities with a recent study conducted by Weinreich et al. (2020) on on-demand, app-based transit services in Texas. An online survey was used to gain the perspectives of transit executives and managers, and semi-structured interviews were conducted to understand the current state of practice relating to assessing the outcomes of on-demand service.

## **Online Survey**

An online survey was administered to transit staff and officials from municipalities in the Washington DC region, including the City of Alexandria, City of Falls Church, and Counties of

Montgomery, Prince George's, Fairfax, Arlington, and Prince William. These jurisdictions follow similar operating rules and practices and have implemented comparable app-based on-demand services with varying levels of transit services. The survey aimed to compare how peers in different agencies approached/considered the assessment of ODT performance. The geographic locations of the survey respondents lead to the identification of the DC Neighborhood Connect ODT system for this case study. According to Weinreich et al. (2020), surveys of this nature can be used to gain insight into the level of ODT implementation or consideration by local governments and transit agencies.

The survey was sent to local transit agencies and municipal staff. The survey population included elected officials and administrative staff—such as transit planners, operations managers, transit managers, or transit directors—who were expected to be familiar with proposed or adopted on-demand transit. Listservs that included emails and names of local transit officials by jurisdictions were used to identify and distribute the survey to potential respondents. The surveys were completed online from November 14, 2022, to January 15, 2023. Due to the low initial response rate, the survey was extended to March 25, 2023, while efforts were made to find and enlist more participants.

A vital drawback of this broad type of canvassing of a public agency is that multiple people receive the survey at once, and internal communication often results in only one respondent self-selecting to respond to the study from this group. This outcome could have reduced the response rate. The questionnaire was developed and pre-tested on colleagues and a research group before it was emailed to each local government in the study and shared via social media. Pre-testing surveys ensured the question order and language were clear. Twenty-eight (28) questions were included in the survey. The survey questions were designed to capture information on the level of interest in replacing existing transit with an app-based, on-demand service, the status of an agency's

implementation of on-demand services, or their plans to implement such a service. The survey included adult residents of the study regions with direct transit experience with on-demand and paratransit services. The online survey was developed in QuestionPro and pilot-tested with the help of colleagues and a Virginia Tech Ph.D. student research group. The survey consisted of 28 questions and was comprised of six sections. A copy of the survey questions can be found in Appendix A.

### **Semi-structured Interviews**

A semi-structured questionnaire was used to interview transit system officials who considered ODT complementary to their core services. The interviews aimed to gather additional data, expert opinions, and motivations on specific matters, such as the factors influencing the outcomes of on-demand paratransit services (Gill et al., 2008). The interviews consisted of ten questions. An initial interview questions/guide was tested in October and November 2022. To recruit survey respondents, I utilized Listservs for the WMATA Joint Coordinating Committee (JCC), the National Capital Region Transportation Planning Board (TPB), and the Conference of Minority Transportation Officials (COMTO). I contacted potential participants through social media platforms like LinkedIn. I conducted semi-structured interviews using an interview guide to ensure relevant follow-up questions were asked in a suitable sequence.

Eleven individuals were selected for an interview based on their direct experience in transit, general knowledge of the research topic and proximity to the study, and experience in related ODT projects. The interviewed individuals were selected by consulting with colleagues and reviewing historical documents. The interviews focused on the three primary performance outcomes associated with ODT. The interviews were conducted from December 2022 through February 2023. An interview question guide was developed with three primary focuses in mind – (1) understanding

existing services, customer travel needs, types of services provided, and travel patterns; (2) obtaining data on the performance measures and outcomes specific to ridership, on-time performance, and operating costs, and (3) obtaining socio-demographic data. The interview question guide and Virginia Tech IRB consent letter are included in Appendix B.

The names and identifiable information will remain anonymous to ensure candid responses from interview participants. Each interview lasted for about an hour. Interviewees also completed the survey. The interviews were conducted at different dates, times, and locations. The selected transit professionals were geographically dispersed across the Washington D.C. region. Additional interviewees were determined using a snowball sampling method by asking interviewees to suggest others working with them to develop and promote app-based, on-demand transit in their area. Calls and emails were also made to local departments overseeing transit operations to identify transit managers or practitioners involved in ODT programs in the D.C. region.

The NTD is the standardized source of comprehensive data used for transit performance measures and analysis by planners and researchers (Lyons & Fleischman, 1991; Gan et al., 2011). Transit agencies must report organization characteristics, services provided, and key performance metrics such as operating expenses, subsidies, and maintenance costs. These metrics are reported by mode per vehicle miles, vehicle revenue hours, safety and security records, facilities and vehicle inventory, and the number of vehicles available for peak service (Administration, 2020; Gan et al., 2011). In Table 11, the performance measure denotes the defining characteristic of the ODT service. The performance goals outline expected changes for each performance measure and the indicators used to measure change. The indicators for evaluation are predefined and include ridership, on-time performance, and operating costs based on the definitions provided by the National Transit Database (NTD). The interview data generated valid and reliable evidence to support the analysis.

## **3.5 Results and Findings**

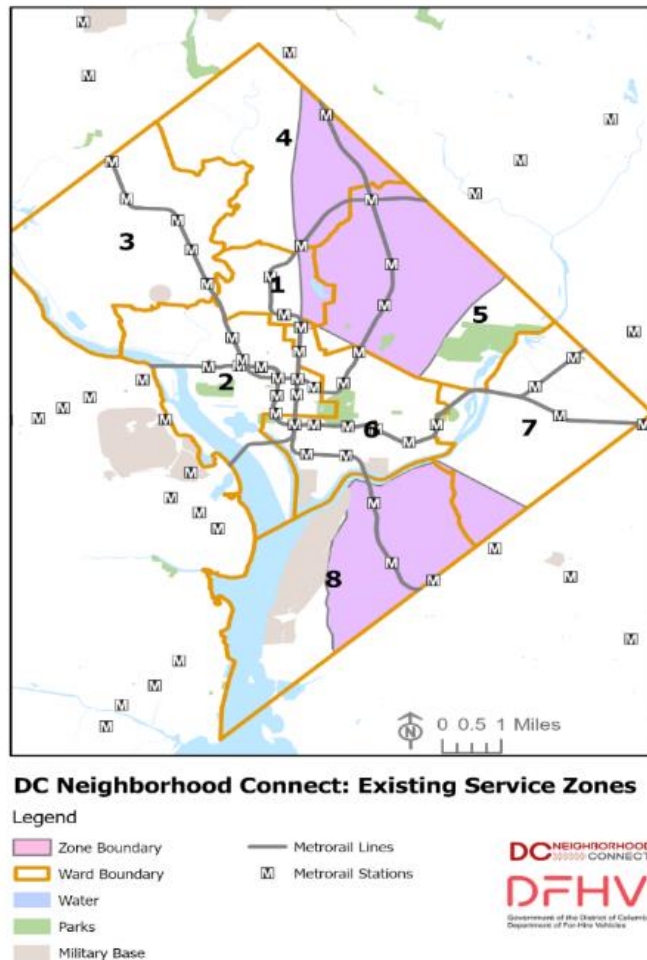
This section presents the results and findings from the survey and interviews. It focuses on the case study of ODT provided by D.C. Neighborhood Connect (DCNC) in Washington, D.C. The section includes descriptive statistics of the DCNC services, zone profiles, and service performance data. It also discusses the outcome of the DCNC case study in Washington, D.C. The survey findings were instrumental in defining the DCNC case study profile and helped identify the typical issues, challenges, and opportunities relevant to the data. Agency data, surveys, interviews, and data from website/internet searches were triangulated to ensure the accuracy of the interviews. This was done to mitigate risks of self-selection and overrepresentation of the data.

### **3.5.1 DCNC Case Study**

The Department of For-Hire Vehicles in Washington, D.C., oversees the regulation of the vehicle-for-hire sector in the district. They also provide a transportation service called DC Neighborhood Connect (DCNC), which operates within three available zones. DCNC is an on-demand shared-ride service that offers curb-to-curb transportation to customers. Over the last year, the DCNC service area has expanded. The study focuses on Northeast and Ward 8 zones.<sup>12</sup> Figure 4 is a map of the DCNC zones for this study. For more information, refer to the 2022 DFHV Microtransit Study.

---

<sup>12</sup> In 2022, the Northeast zone was divided into two separate zones by redefining boundaries and creating a Southern zone. Per Davis and McKeeman, 2023



*Figure 4 DCNC Service Area Map for 2021*

DC Neighborhood Connect (DCNC) service was initially launched in 2019 as “DC Microtransit.” It was made available to the public in two zones, including Zone 1 (Northeast Zone), which covers parts of Wards 1, 4, and 5 in the Northeast of the City. Zone 1 was the first area to receive the service. Due to the COVID-19 pandemic, the service was modified in 2021 and relaunched. A new zone covering most of Ward 8 was added in 2021. Table 14 provides a summary of the DCNC service. The service is available every day of the week with the following operating

hours: Monday to Thursday from 6:30 a.m. to 10:00 p.m., Friday from 6:30 a.m. to 12:00 a.m., Saturday from 8:00 a.m. to 12:00 a.m., and Sunday from 8:00 a.m. to 10:00 p.m.<sup>13</sup>

**Table 13 Summary of DCNC Service Characteristics**

<b>Zone</b>	<b>Boundaries</b>	<b>Started</b>	<b>Service Area (Sq. Mi)</b>	<b>Average Daily Ridership (2021)</b>
<b>Northeast Zone (Zone 1)</b>	Wards 1,4 & 5, including Michigan Ave, Eastern Ave NE, and Georgia Ave NW, by Florida Ave NE, Bladensburg Ave	2019	11.3	122
<b>Ward 8 Zone</b>	Ward 8 East of the River Zone.	2021	7	25

*Source: DC Department of For Hire Vehicle (DFHV).*

The DCNC is a contracted transportation service that partners with Taxi Transportation Service (Transco), a local taxicab provider,<sup>14</sup> and Via, which provides the digital infrastructure for on-demand transit and microtransit services.<sup>15</sup> Customers who do not have smartphones can request a ride by calling the Transco call center. The DCNC services operate seven days a week, from 6:30 am to 10:00 pm on weekdays and from 8:00 am to midnight on weekends. Starting from 2020, the rides on DCNC have been free of charge. In 2021, the service operated with a fleet of eighteen dedicated vehicles, consisting of 12 Ford Transit Cutaways and 5 Dodge Caravans.<sup>16</sup>

## **Northeast Zone**

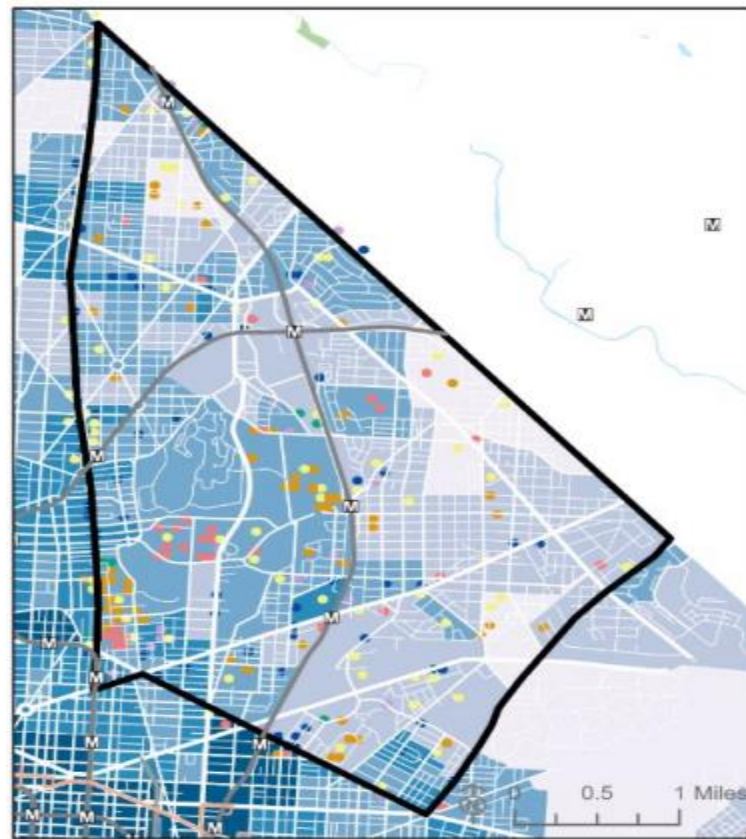
The Northeast zone of the District is situated between Georgia Avenue in the West, Eastern Avenue in the East, and Florida Avenue and Bladensburg Road in the South. The zone covers three District wards, including parts of Ward 5, Ward 4, and Ward 1 (Figure 5).

<sup>13</sup> Microtransit in DC Study. (2022). Retrieved December 15, 2023, from [Microtransit in DC – Existing Conditions Memo \(mwcog.org\)](#)

<sup>14</sup> Taxi Transportation Service (Transco) is a taxi operator providing for-hire ride services in the D.C. area.

<sup>15</sup> Via is a private mobility provider that operates an on-demand and dynamic network of partners. The Via mobile app connects multiple passengers sharing the same vehicle to similar origins or destinations. Retrieved December 15, 2023, from [Via announces expansion to Alexandria, Virginia \(ridewithvia.com\)](#)

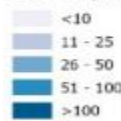
<sup>16</sup> Davis and McKeeman, 2023



**DC Neighborhood Connect: Northeast Zone**

Legend

Jobs + Population / Acre



Activity Generators



Source: DC Department of For-Hire Vehicles (DFHV)  
 Figure 5 Northeast Zone

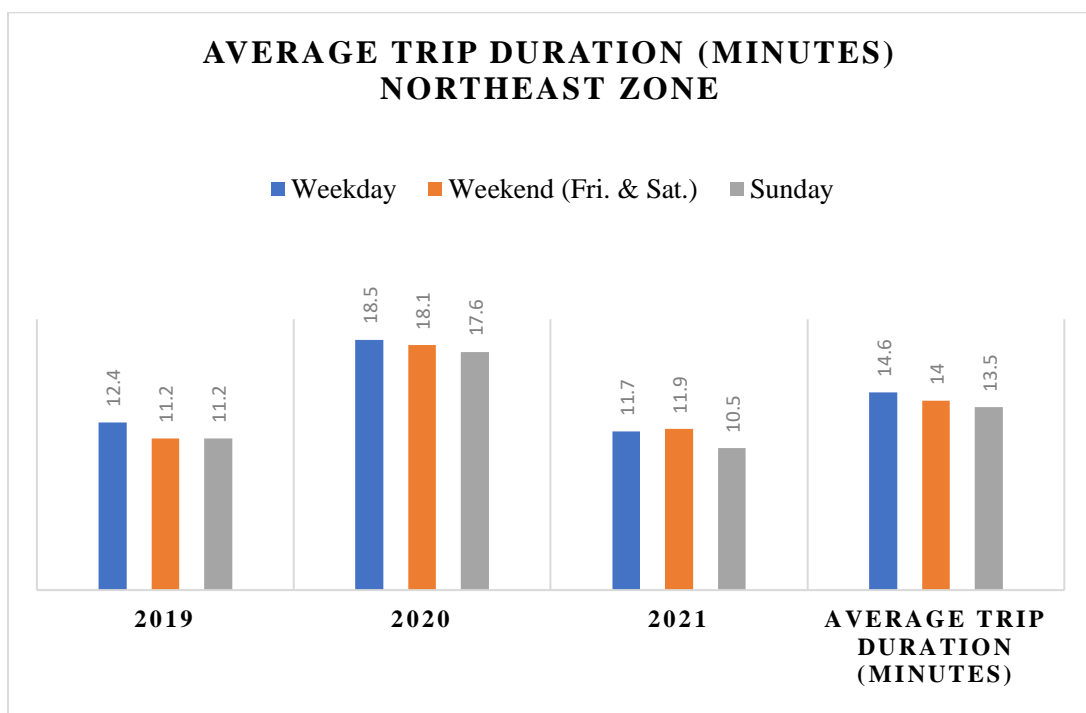
The zone is 11.3 square miles and is home to approximately 128,200 residents, around 19 percent of the District’s population. Six Metrorail stations in this zone provide access to the Red, Yellow, and Green Metrorail lines. Around 76 percent of the residents in this zone are people of color, while 18 percent are low-income. Data shows that about 76% (10,073 of 13,267) of trips completed between June and November 2021 started and ended within the Northeast zone.<sup>17</sup>

<sup>17</sup> [Microtransit in DC – Existing Conditions Memo \(mwcog.org\)](https://www.mwcog.org/)

## Operational Performance

DFHV staff shared operational performance data consistent with data published in a microtransit study on D.C. sponsored by the Metropolitan Washington Council of Government (MWCOG).<sup>18</sup> The operating performance data is discussed below.

Figure 6 shows the on-time performance, including the average trip duration of 14.6 minutes on weekdays, 14 minutes on weekends (Friday and Saturday), and 13.5 minutes on Sundays.



*Figure 6 Average Trip Duration*

Figure 8 below shows that the average wait time was 15.9 minutes on weekdays, 19.8 minutes on weekends, and 15.5 on Sundays.

<sup>18</sup> Foursquare ITP (2022, June 1). *Microtransit in DC Study*. Mwcog.org. Retrieved November 2, 2022, from [https://www.mwcog.org/assets/1/6/DC - TLC FY22 Microtransit in DC Final Report.pdf](https://www.mwcog.org/assets/1/6/DC_-_TLC_FY22_Microtransit_in_DC_Final_Report.pdf)

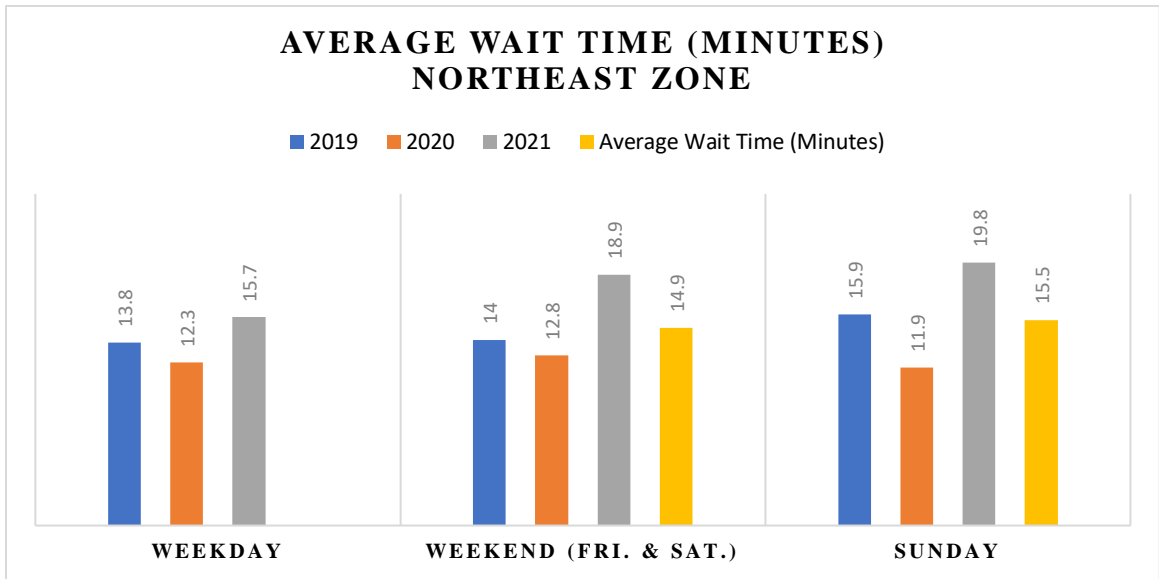


Figure 7 Average Wait Time

Figure 9 below indicates that the average daily ridership from 2019-2021 was 111 on weekdays, 88 on weekends, and 62 on Sundays. Ridership dropped in 2020 because of the COVID-19 pandemic.

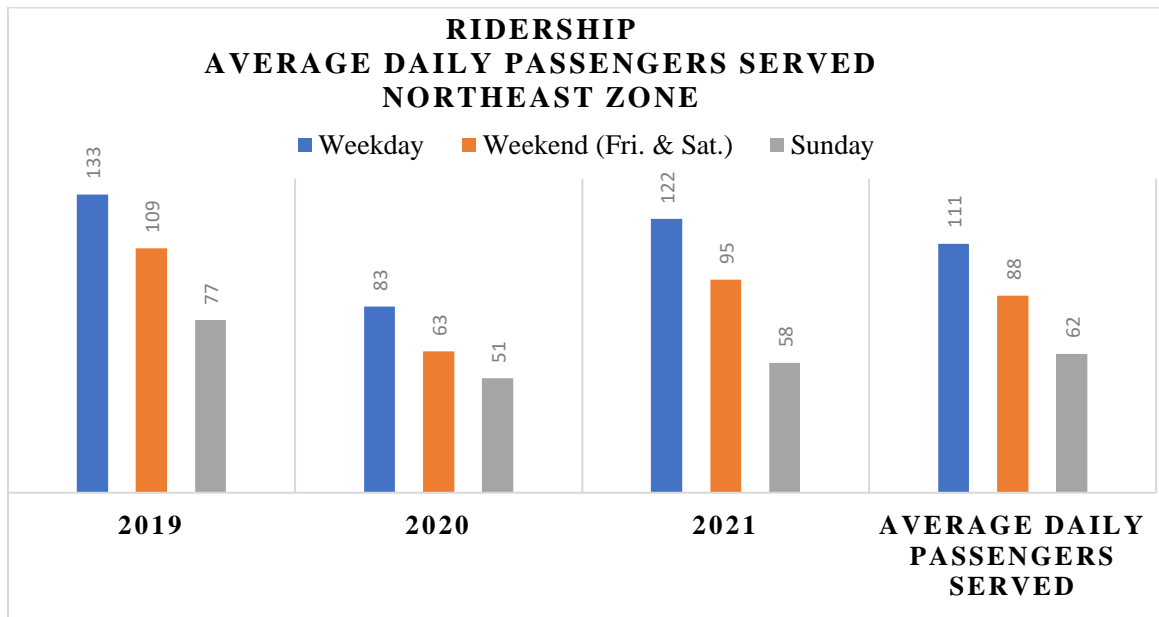
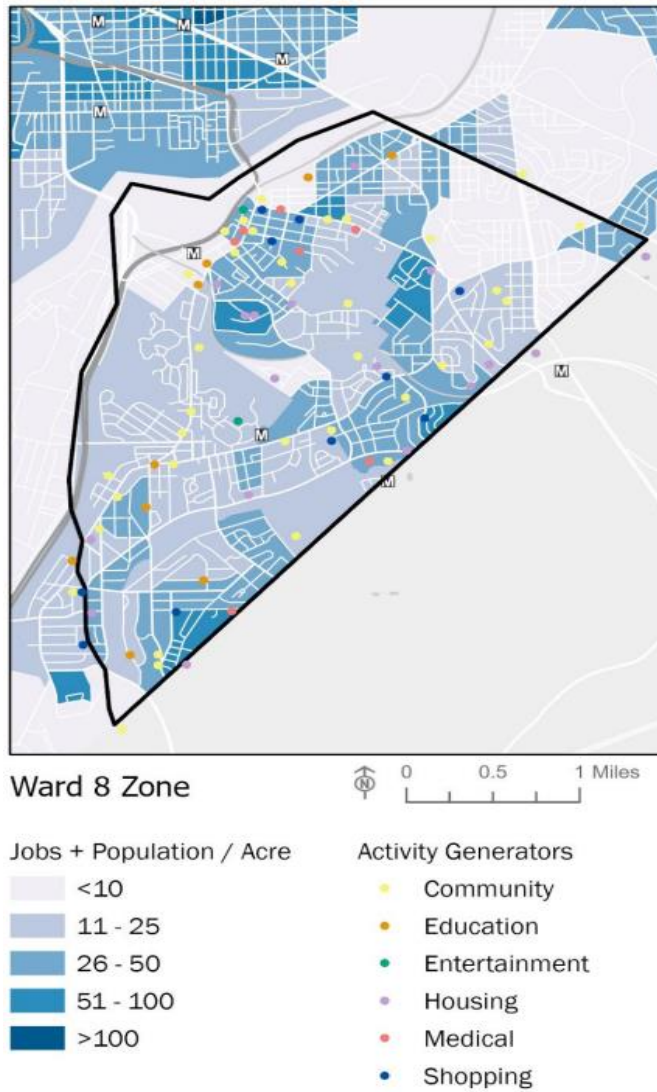


Figure 8 Average Daily Ridership

**Ward 8 Zone**

DCNC service in Ward 8 started in 2021. The Ward 8 zone is in southern Washington, D.C. It is bounded by Pennsylvania Avenue and the Potomac River in the north, Southern Avenue in the east, and Anacostia Freeway in the west. It covers an area of seven square miles, including a large part of Ward 8 and a small portion of Ward 7 (Figure 9).



Source: DC Department of For Hire Vehicle (DFHV). *Microtransit in DC.*  
 Figure 9 Ward 8 Zone

DCNC bridges the transit gap in Ward 8, while ODT connects underserved residents to jobs and services in other areas. The Anacostia River divides Wards 7 and 8, and Ward 8 is a historically disadvantaged community with limited public transit access to/from the downtown area (Bonner &

Miller-Hooks, 2023). This zone has a higher concentration of vulnerable populations than the Northeast zone.<sup>19</sup> The population of this area is made up of people of color, accounting for almost 97 percent of the total population. Approximately 47 percent of the population is considered low-income. For instance, the zone has a lower median income of about one-third of the people in the rest of the city. It also has fewer job opportunities, with only 10,200 jobs available, approximately 1% of the total jobs. District.<sup>20</sup> Over two-thirds of households in this area have low car ownership, with either zero or just one car per household.<sup>21</sup> Residents in Ward 8 are facing significant challenges with persistent obstacles to economic participation and inclusion. DCNC addresses equity needs in this part of Washington, D.C. A City official acknowledged that the DCNC service provides a crucial lifeline to opportunities for many people. By increasing access to job opportunities and reducing unemployment, the program addresses transit equity issues and mitigates the impacts of disparities in the City.

## Operational Performance

According to the Microtransit in DC report, the average trip duration 2020 was approximately 14 minutes on weekdays, 17.7 minutes on weekends, and 14.5 minutes on Sundays. In 2021, the average trip duration was reduced significantly, with 8.9 minutes on weekdays, 9.2

---

<sup>19</sup> Davis, Charles, and Alanna McKeeman. "Microtransit in DC Study" National Capital Region Transportation Planning Board Regional Public Transportation Subcommittee, January 24, 2023. Retrieved December 29, 2023, from <https://www.mwcog.org/file.aspx?&A=iwwQK9yFNHLvBiCM14wiVdpeEAuVWoKT%2bDI2YWGH4fM%3d>; Vitka, Will. "DC Expands Neighborhood Connect Shuttle Service in Northeast and Northwest." WTOP News, May 12, 2022. <https://wtop.com/dc/2022/05/dc-expands-neighborhood-connect-shuttle-service-in-northeast-andnorthwest/>.

<sup>20</sup> USDE (n.d.). *District of Columbia PYs 2020-2023: WIOA State Plan Common Elements*. Wioaplans.ed.gov. Retrieved December 29, 2023, from

<https://www.mwcog.org/file.aspx?&A=iwwQK9yFNHLvBiCM14wiVdpeEAuVWoKT%2BDI2YWGH4fM%3D>

<sup>21</sup> DFHV (2023, January 1). *Microtransit in DC Study - Existing Conditions Memo*. Mwcog.org. Retrieved December 29, 2023, from

<https://www.mwcog.org/file.aspx?&A=iwwQK9yFNHLvBiCM14wiVdpeEAuVWoKT%2BDI2YWGH4fM%3D>

minutes on weekends, and 7.7 minutes on Sundays (see Figure 10 for a visual representation of the data).

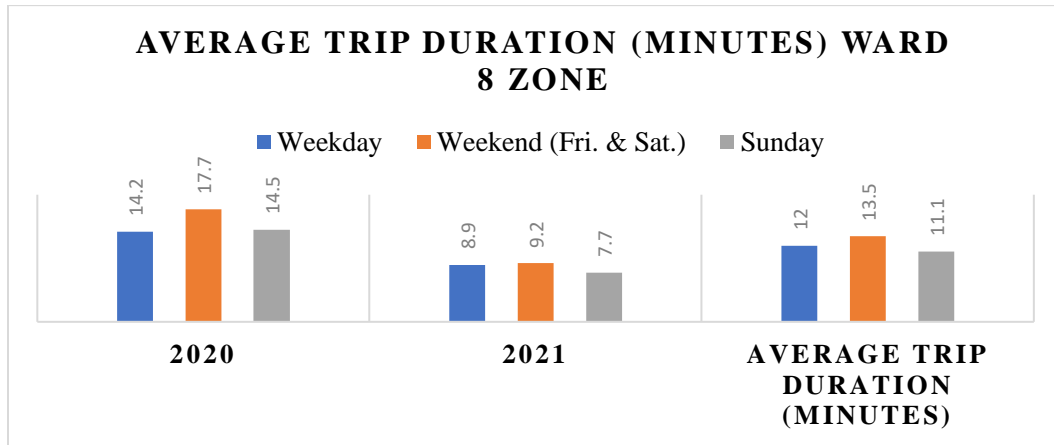


Figure 10 Average Trip Duration

Figure 11 shows that the average wait time for weekday, Saturday, and Sunday services in 2021 was approximately 9 minutes. Although the wait time increased in 2021, it remained around 11.5 minutes for Saturday and Sunday services. So, there was an increase in wait time in 2021, but it did not significantly impact the wait times for weekend services.

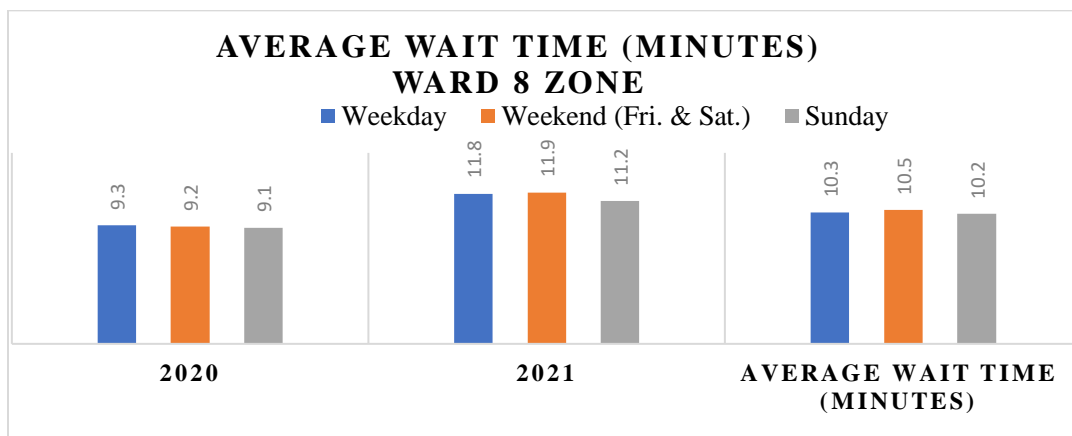
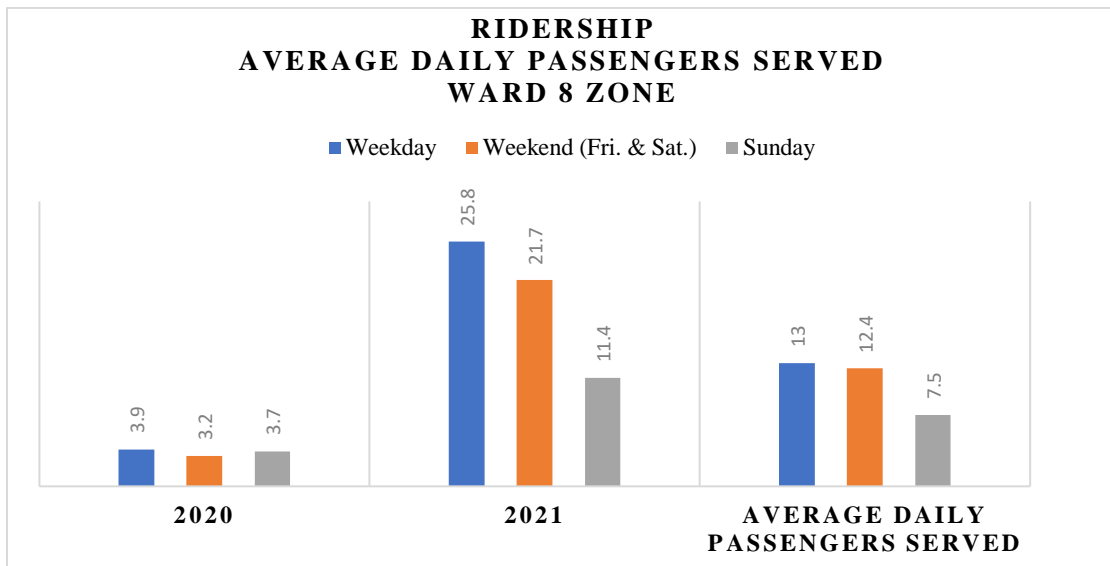


Figure 11 Average Wait Time

Figure 12 shows that the average daily ridership 2020 was 3.9 on weekdays, 3.2 on Saturdays, and 3.7 on Sundays. In 2021, the ridership increased significantly to an average of 25 passengers on weekdays, 21 on Saturdays, and 11.4 on Sundays.

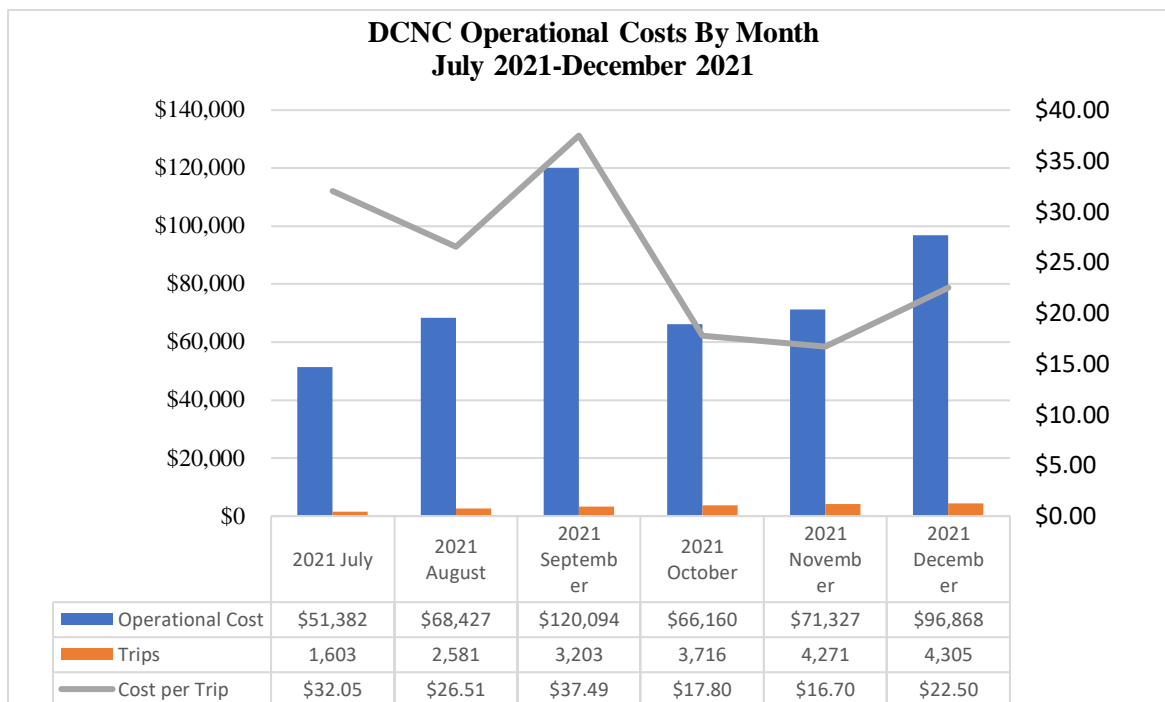


*Figure 12 Ridership Average Daily Passengers Served*

## Operating Costs

The cost of each passenger trip is a key factor that helps transportation agencies determine the funding required to operate a specific ODT zone compared to other transit services. Based on the operating data for the first half of 2021, the monthly operational costs for DCNC are approximately \$80,000, which averages \$26 per trip (Figure 13). The cost per DCNC trip can vary based on ridership and other factors, but it is more expensive than the cost per trip for fixed-route bus services. For instance, the operating cost per passenger trip for Metrobus ranges between \$3.50 to \$7, depending on the type of service.<sup>22</sup> It is worth noting that higher operational costs can become a financial burden to the agency in zones with low ridership.

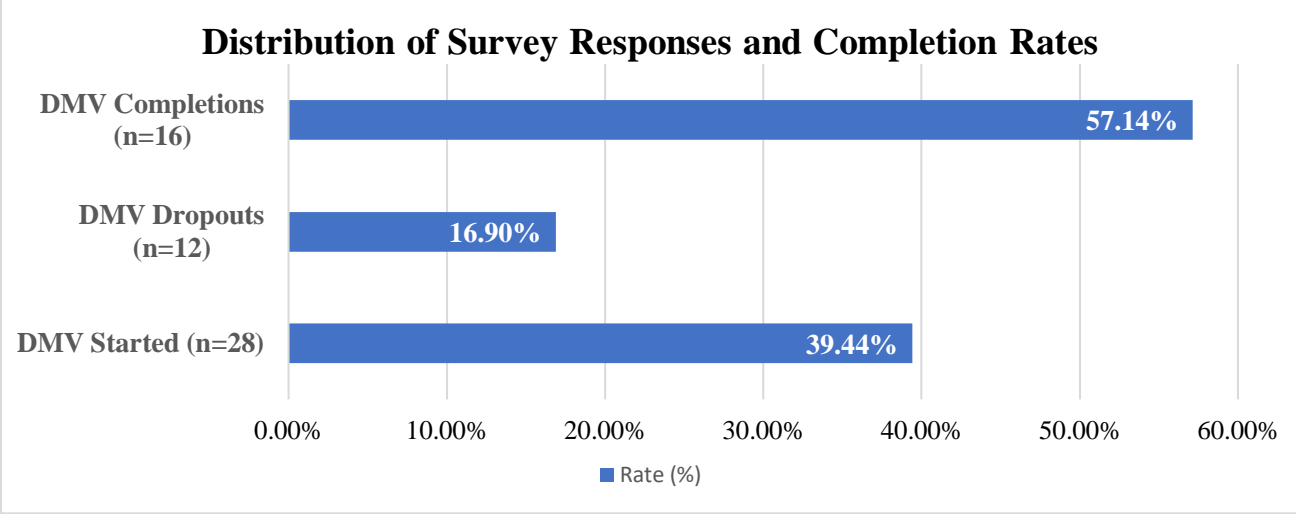
<sup>22</sup> WMATA (2020). Framework for Transit Equity: Metrobus Service Guidelines. Retrieved December 29, 2023, from <https://www.wmata.com/about/board/meetings/board-pdfs/upload/4A-Metrobus-Service-Guidelines-CORR.pdf>



*Figure 13 Operating Costs*

### 3.5.2 Survey Findings

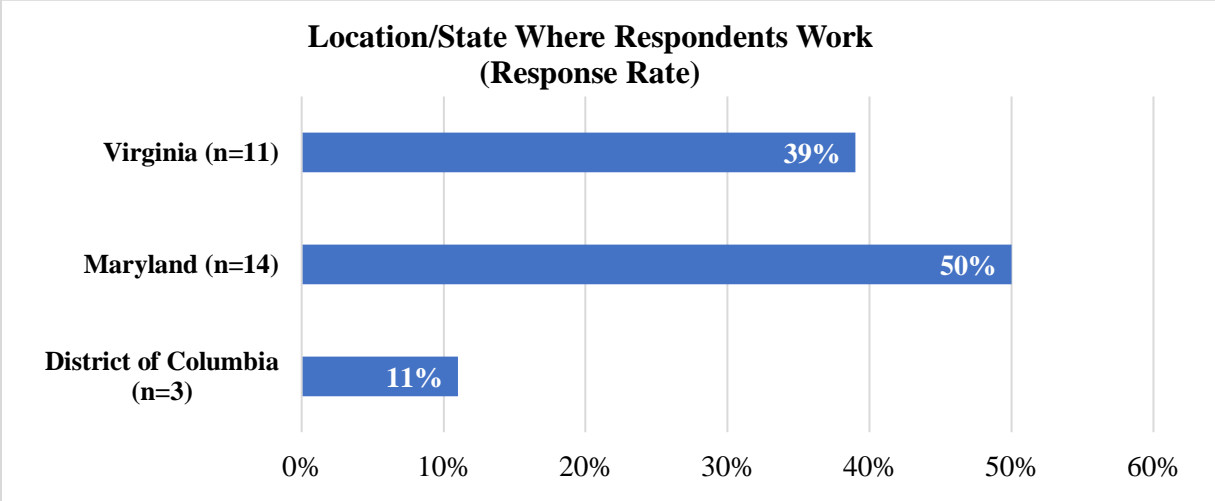
The survey aimed to gather information on the current state of app-based and on-demand transit systems. The specific goals of this questionnaire were to learn about ODT adoption in Washington D.C. with the following objectives: (1) to understand how ODT improves transit outcomes, (2) to gain knowledge on the performance outcomes for DCNC services in terms of ridership, on-time performance, and operating costs, and (3) to document the technological features of on-demand transit services and how they impact service performance outcomes. This information can help transit agencies, planners, and policymakers understand existing practices and identify improvement areas. Figure 14 provides an overview of the completion rates.



*DMV = Survey Respondents Living or working in the Washington D.C Metropolitan Area  
 Figure 14 Distribution of Survey Responses and Completion*

***What state do you work in?***

A total of 71 completed responses; 28 started and did not complete the survey, and 12 dropped out but answered some of the survey questions. Only 16 responses were achieved by people who worked or lived in the Washington DC region, respondents who selected the District of Columbia, Virginia, and Maryland. Based on the 16 survey respondents, 50% indicated they work in Maryland, 39.29% in Virginia, and 10.71% in Washington, D.C. (Figure 15).



*Figure 15 Survey Respondents by Work Location.*

***Please indicate the type of geographic area your organization serves or provides transit services to***

Survey respondents were asked about the geographic settings where their organizations provided transit services. Figure 16 shows that of the 26 responses to this question, 15% (n=4) selected suburban, 31% (n=8) indicated a mix of urban/rural, and 54% (n=14) noted urban. The data fits the target agency type for this study.

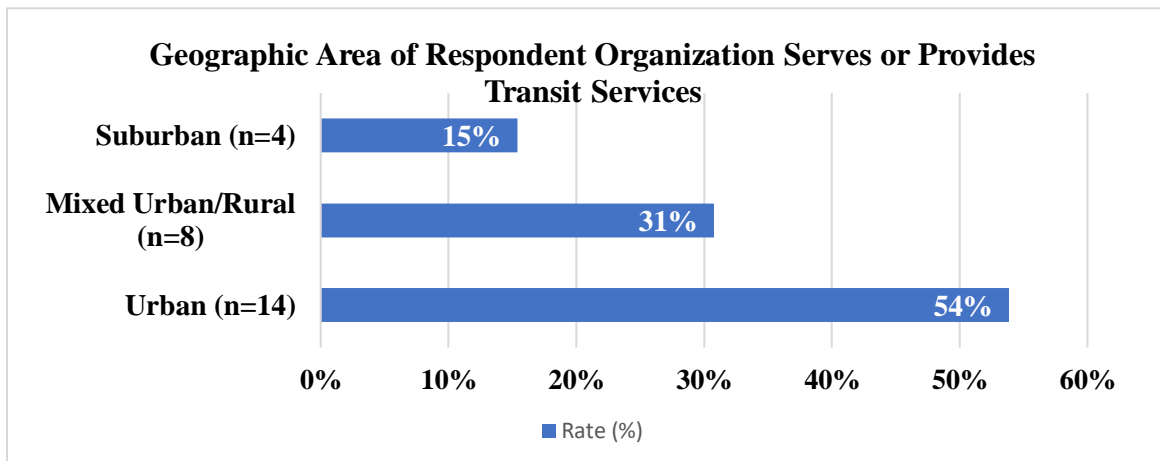


Figure 16 Geographic Area of Transit Services

*Please indicate the category that best describes your agency*

According to Figure 17, 58% of respondents work for public/transit agencies, 21% for local/municipal transit agencies, 13% for transit authorities, and 8% for other agencies.

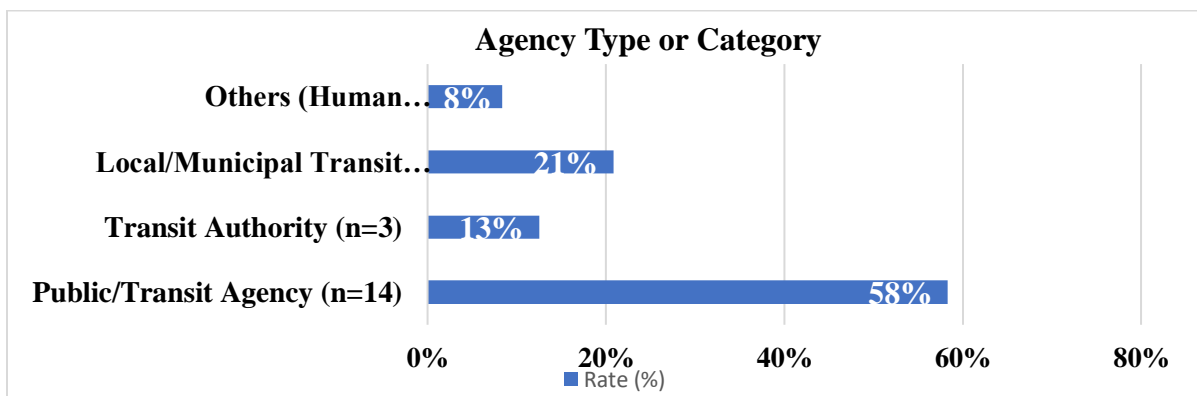


Figure 17 Agency Type or Category

*To what extent does your organization use the following transit-related variables for decision-making? (1- Not used at all - 5-Extensively used; Don't know)*

According to the survey, participants reported that transit agencies or providers utilized four key measures to monitor and track ODT service performance. These locations include on-time performance, reliability,<sup>23</sup> ridership, and operating costs. Approximately 71% of the participants reported on-time performance, 65% reported reliability, 70% reported ridership, and 43% reported operating costs.

Below is Figure 18, which compares respondents' opinions regarding their agency's use of critical performance measures such as on-time performance, ridership, and operating costs for decision-making.

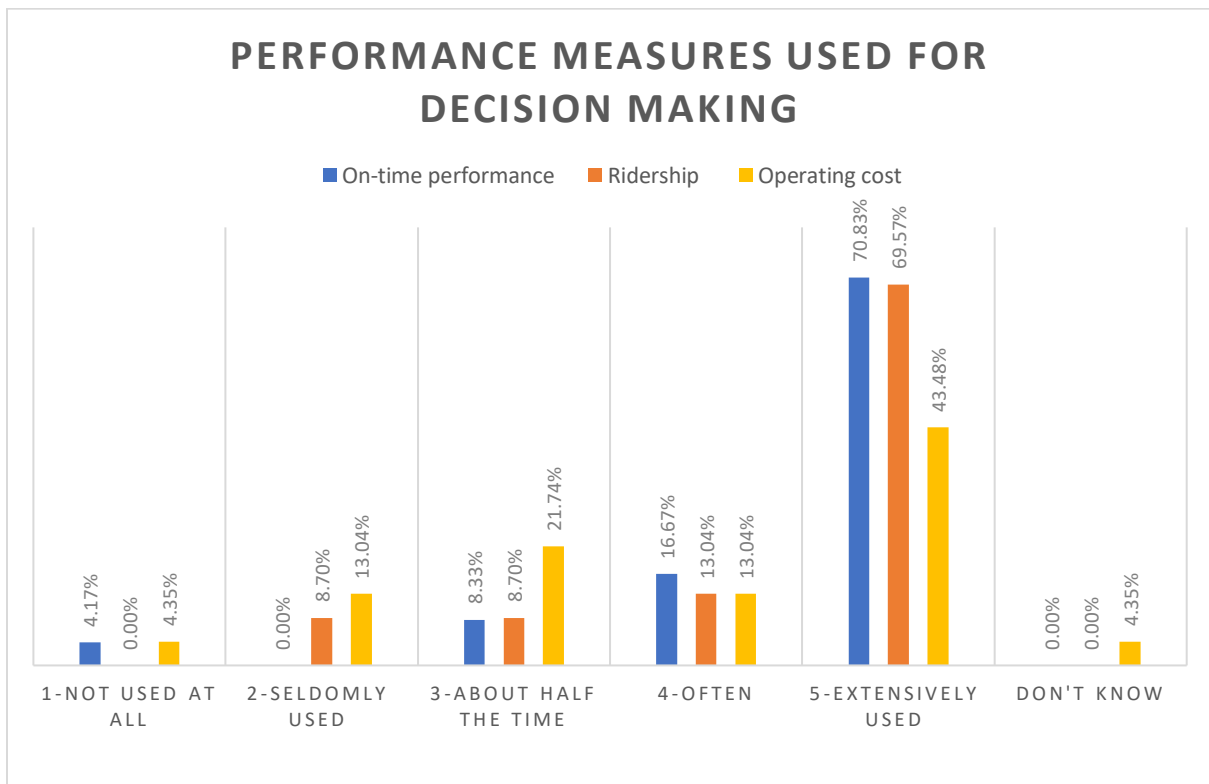
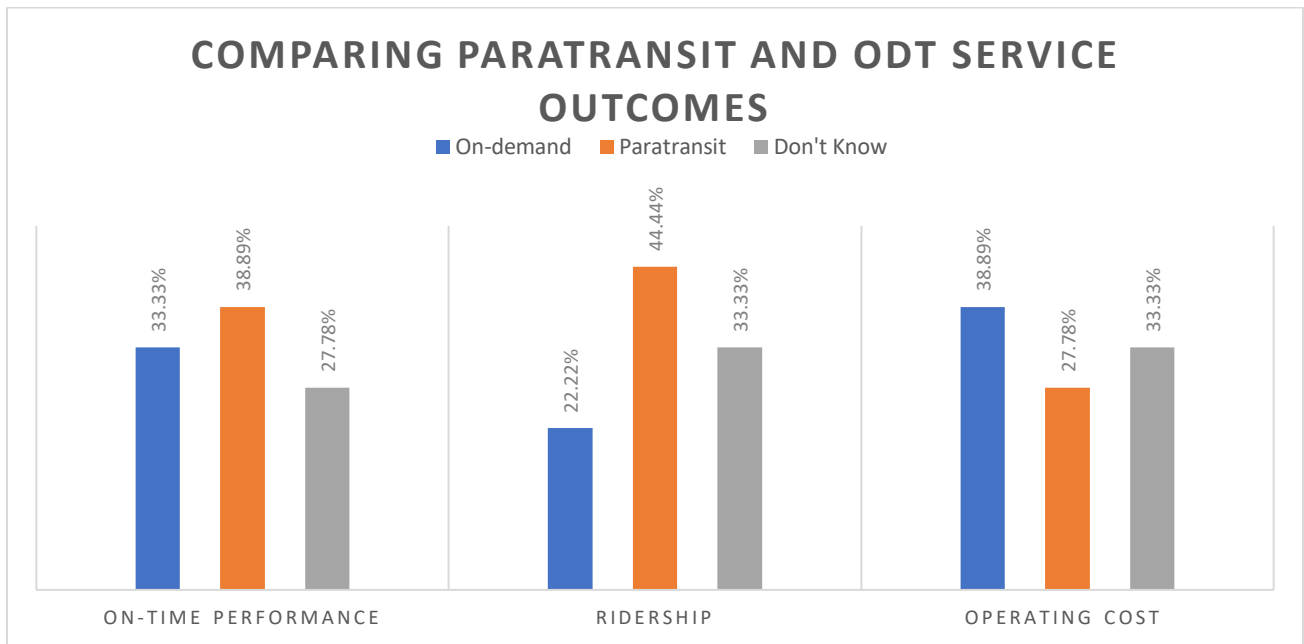


Figure 18 Performance Measures Used for ODT Decision-Making

<sup>23</sup> Reliability is determined based on the number of missed trips, delays, wait time, and travel time.

Additional findings from the survey are discussed below. According to the study, transit agencies and municipalities use different strategies to provide on-demand trips. When asked about on-demand and paratransit services, 38.8% (n=7) believed that paratransit services had better on-time performance, while 44.4% (n=8) indicated paratransit services had better ridership. On the other hand, 38.8% (n=7) believed that on-demand services were better in terms of operating costs. However, many respondents were uncertain and needed to learn about these factors (Figure 19).



*Figure 19 Opinion on ODT and Paratransit Cost Comparison*

It is important to note that out of the 21 respondents from municipalities who participated in the survey, 24.39% use TNCs, 24.39% use taxis, 24.39% use cutaway vehicles, and 19.51% use vans to provide on-demand services.

### **3.5.3 Summary Findings from Interviews**

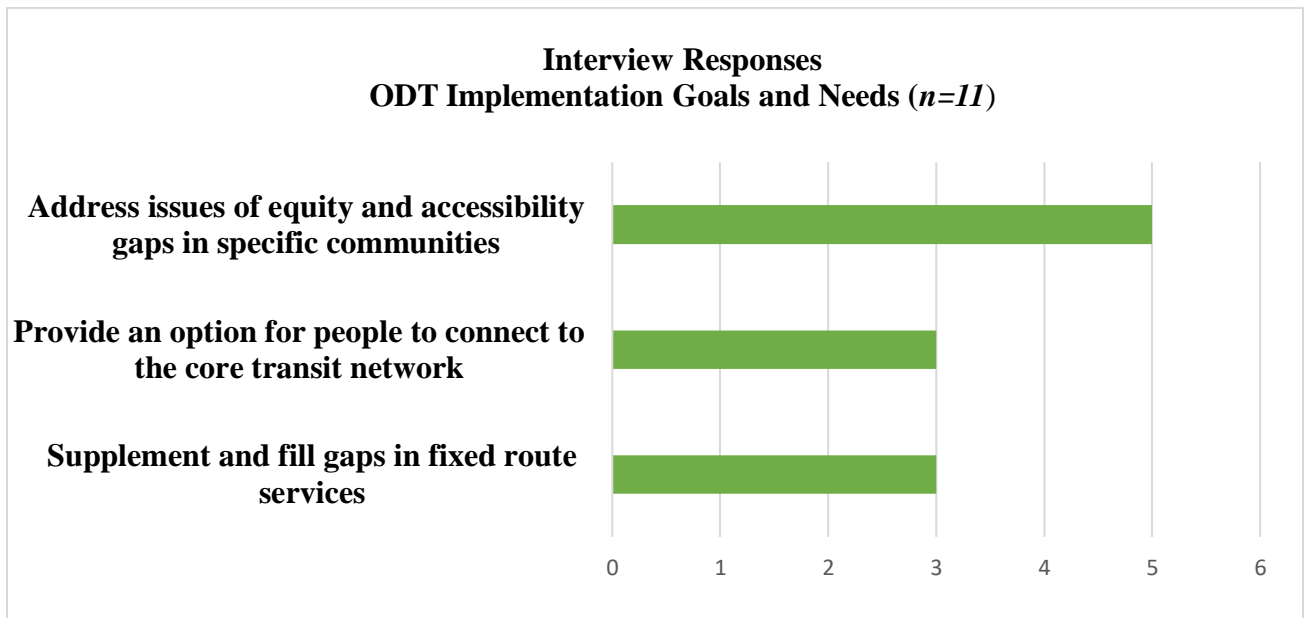
In the section below, I will discuss the following topics related to ODT implementation: (1) the goals and objectives for implementing ODT, (2) the impacts of ODT in addressing community

transportation needs, and (3) the need to gather data on service variables, including service area characteristics and performance measures, to assess ODT outcomes.

Eleven individuals were interviewed for this study: five males and six females, all with transit experience. Seven individuals had more than 16 years of experience in transit at the local and regional levels. Two participants had over 20 years of experience overseeing transit operations and policy as senior managers. One participant was a senior planning official with about ten years of transit experience; another was a senior manager with 12 years of transit experience. Of the 11 participants, seven were directly involved in planning and designing ODT systems in the Washington DC area, while four held senior management roles with policy and management oversight of transit operations. All participants live and work in the Washington, DC, region. The participants' range of planning, policy, and operations experiences is significant because it indicates the relevance of their expertise and understanding of the topic. It is important to note that all interview citations in this study are anonymized.

## **ODT Implementation Goals and Needs**

During the interviews, participants were asked about the goals and objectives for implementing ODT in their jurisdictions and to elaborate on program priorities. All eleven participants provided a combination of varied factors to this question. The standard answer among all participants was that the goals and priorities of their ODT programs are to supplement existing fixed route services. Figure 20 summarizes the three key themes that emerged from the interviews about the goals and needs of ODT service implementation. These themes include filling gaps in areas where the fixed route was unavailable, connecting people to the core transit network, and addressing equity and accessibility gaps in specific communities.



*Figure 20 Summary of Key Themes from Interviews*

During interviews, an official noted that microtransit aims to expand the operating hours of available transportation services, connect to fixed-route services, provide an alternative to paratransit, and overcome existing limitations of bus transit systems in the County. This finding confirms what is already discussed in the literature: ODT is flexible and can be customized to meet the different transportation needs of a community. The findings support the belief that ODT offers flexible travel options through app-based services, allowing point-to-point and door-to-door rideshare, first-last mile transportation, and access to fixed route transit. This has been discussed in the studies conducted by Weinreich et al. (2020) and Ma et al. (2020).

### **Impacts of ODT on Addressing Community Transportation Needs**

Responses to questions on the impact of ODT in addressing community transportation needs were fluid and varied. Some participants acknowledge that ODT was vital to those who used the services, especially in communities with limited bus services. For instance, a few officials argued that many seniors and individuals with disabilities use the service despite low ridership. Another participant elaborated on the equity needs of communities currently serviced by ODT services.

However, some of the participants seemed to be okay with how the service was performing in terms of usage or the design of the service if the service was available to residents who needed it. For example, a senior official stated that ODT *“provides badly needed transit coverage in the community, making it easy for residents to access key destinations in a safe and reliable system.”*

Many practitioners shared that ODT impacts can be viewed through an equity lens. When asked how ODT aligns with the broader transportation needs in a particular community, an official noted that *“the impacts are to prioritize transit investments, elevate equity discussions, and improve connectivity as part of current and future growth and investment decisions.”* A few have a different view on transportation needs and impacts. For instance, a manager said, *“ODT is transformative, and the most significant impact is that ODT enables technology innovations, improves transit planning, and delivers safe and reliable options that people have asked for many years.”*

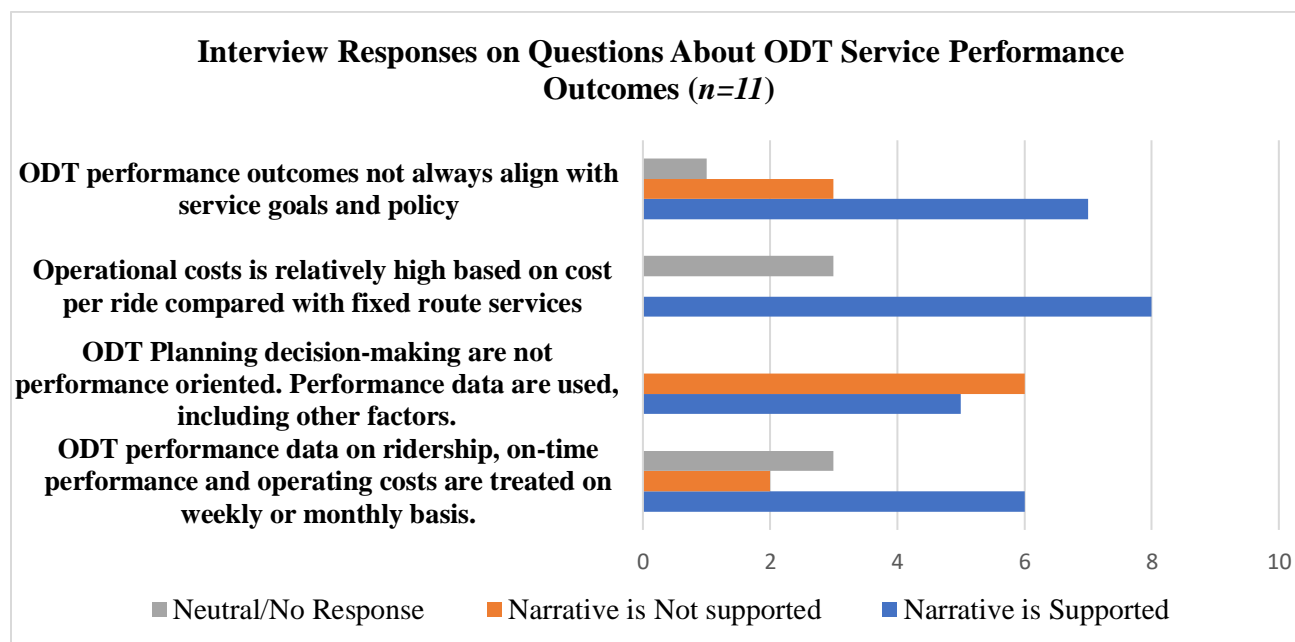
While the participants had varied notions about the impacts of ODT in addressing community transportation needs, the need for ODT adoption is evident based on the interview responses. Participants recognized that some ODT services needed to be fully aligned with travel needs, especially in areas with a limited span of service and a lack of weekend service.

## **ODT Service Performance Outcomes**

The essential purpose of the service outcome questions was to understand how performance management is used by transit providers in ODT implementation. The aim was to gather information about how performance measures are employed to monitor and evaluate the outcomes of ODT service and to gain insight into how performance data is used in the planning and service design. Additionally, the officials' opinions and perceptions regarding ODT performance were explored compared to fixed-route buses or traditional paratransit services. The discussions on performance primarily focused on ridership, on-time performance, and operating cost factors.

Figure 21 outlines the four main themes that emerged from the interviews conducted with local officials. However, the officials had mixed responses regarding these themes:

1. All the participants mentioned monitoring performance data on ridership and on-time performance every week while operating costs are tracked monthly.
2. The officials stated that they use performance data for planning and decision-making purposes, but they also consider other factors besides performance when making operational decisions and designing services. The responses suggest that ridership is a critical performance metric compared to cost per trip and the allocation of subsidies.
3. The operating costs of ODT were high when compared to fixed route services such as buses and rails, based on cost per ride.



*Figure 21 Interview Responses to Questions About ODT Performance*

The general perception is that the performance of ODT only sometimes aligns with service goals and policies and could be seen as a politically sensitive topic. For instance, a senior official mentioned that OTP (On-Time Performance) and cost are not critical when designing and implementing ODT service. The aim is to provide a social service to those without vehicles who

must get to their jobs on time. She indicated that her department is trying to offer and has budgeted for this service.

Regarding how ODT performance is measured, a planning staff member noted that performance numbers do not count because they are still experimenting with ODT and will take what they get regarding ridership and cost. In the same vein, one of the participants said, *“I am more concerned about the increase in paratransit cost and longer wait times for ODT. High OTP is meaningless if people wait more than 15 minutes for their bus. I always emphasize reducing wait time, travel time, and carrying more short trips within the zone.”*

### **3.5.4 Summary Findings from the DCNC Case Study**

This section summarizes the findings from the DCNC case study and highlights key findings from the study data.

#### **How does ODT improve transit outcomes?**

DCNC services operate in regions highly suitable for microtransit, aiming to provide access to employment opportunities and address equity issues in the Northeast and Ward 8 zones. The zones connect low-income and minority residents with riders and opportunities. The Mayor stated that DC Neighborhood Connect was established to provide more transit options and improve transportation equity for residents.<sup>24</sup> Like other ODT services across the Country, DCNC offers first and last-mile transportation services and connects to different forms of transit. DCNC’s services also complement public transit options like buses or trains. Customers use microtransit services for

---

<sup>24</sup> Executive Office of the Mayor (2022, May 11). *Mayor Bowser Announces Expansion of Neighborhood Connect Service in Northwest and Northeast*. Mayor.dc.gov/. Retrieved December 29, 2023, from <https://mayor.dc.gov/release/mayor-bowser-announces-expansion-neighborhood-connect-service-northwest-and-northeast>

shorter trips to bus and rail hubs and trips within ODT zones. On average, the trip distance on DCNC is about 3 miles. DCNC customers will substitute shorter bus and rail trips with microtransit service within the ODT zones. On average, the trip distance on DCNC is about 3 miles.<sup>25</sup>

As per the feedback received from the staff during the study, the ODT service is instrumental in filling the gaps in Metrobus, DC Connector, and MetroAccess route services. It is important to note that this service does not intend to replace any existing bus service but to improve accessibility to the city's underserved areas. A spokesperson stated that ODT *“aims to offer residents more travel options as it is a reliable and flexible service. This microtransit service connects people to shopping, healthcare, schools, and entertainment, allowing them to choose when they want to travel.”*

### **What are the performance outcomes for DCNC service regarding ridership, on-time performance, and operating costs?**

DCNC’s ridership has steadily grown, especially in the Northeast zone. This area has a high concentration of jobs and is linked to six Metrorail stations. However, on-time performance has been mixed. Data supplied by the DFHV shows that between June and November 2021, DCNC provided 16,622 passenger trips in the Northeast Zone or an average of 2,060 monthly passenger trips. The Northeast has high ridership due to high concentrations of trips starting and ending within neighborhoods in the zone, indicating strong demand and accessibility. Ward 8 service has also seen an increase in ridership. Despite solid ridership demand, the on-time performance and reliability of the service were negatively impacted. This is due to longer wait times, particularly in the Northeast zone. In 2021 and 2022, the system’s average wait time increased from 13 minutes to 25-30 minutes compared to the previous year. This significantly affected the service reliability as some passengers had to wait longer for a ride, especially during peak hours. According to the “Microtransit in D.C. –

---

<sup>25</sup> Foursquare ITP (2022, June 1). *Microtransit in DC Study*. Mwcog.org. Retrieved November 2, 2022, from [https://www.mwcog.org/assets/1/6/DC - TLC FY22 Microtransit in DC Final Report.pdf](https://www.mwcog.org/assets/1/6/DC_-_TLC_FY22_Microtransit_in_DC_Final_Report.pdf)

Final Report” for 2021, the operational cost per passenger trip varies from \$19 to \$25. This cost is notably higher than the cost per passenger trip on the Metrobus, which ranges from \$5 to \$7.

### **What are the technological features of on-demand transit services, and how do they impact the performance outcomes of such services?**

DCNC uses real-time dynamic technologies to provide on-demand micro transit. DHFV has contracted with Via and uses the Via app as the digital infrastructure to interface with passengers and drivers. Studies have shown that these technology systems allow for the delivery of flexible, on-demand transit services (Bürstlein et al., 2021; Sanallah et al., 2021; Mulley & Nelson, 2009). Passengers use the Via app to select their pick-up and drop-off location, make payments, plan trips, and monitor their rides, and Via’s algorithm allows multiple riders to share a single vehicle. Drivers also use the app interface to complete trip requests, route (navigation), and communicate.

Like many others available on the market, this digital transportation system is utilized by taxis to provide on-demand services. DCNC partnered with Transco, a private taxi provider, to operate the DCNC services using the Via app. The App has features where passengers can be guided to a nearby virtual bus stop served by Via for convenient pick-up and drop-off. As mentioned in Chapter 1, Via is an example of a Real-Time Dynamic Dispatching and Scheduling technology that addresses real-time trip booking and routing optimization by adjusting routes and schedules dynamically for point-to-point transit, using sophisticated algorithms to optimize route, routing, and service delivery, making it more efficient. This allows for fast, dynamic, and efficient shared rides without unnecessary detours that take riders off their intended route.

The findings of the case study exhibit some similarities with the results of the survey. According to a senior program manager at the DC Department of For-Hire Vehicles (DFHV), the primary goal of implementing DCNC is to provide affordable, accessible, and on-demand

transportation to low-income communities and neighborhoods with limited transportation options. Although the District does not offer paratransit services like MetroAccess, DCNC fills gaps in both fixed route and paratransit services. It has no restrictions on who can use it, unlike MetroAccess ADA paratransit and Transport DC, which have registration restrictions.

Based on agency data and the interviews, the following points outline how technology has impacted DCNC performance outcomes. ODT has:

1. Helped address equity and accessibility challenges by providing flexible transit options in areas previously underserved.
2. Promoted economic growth and empowerment by connecting people with more jobs and delivering a higher quality transit option with a comparable cost to paratransit or related bus services provided by Metrobus and MetroAccess.
3. Enhanced transit access and reliability to increase ridesharing through innovative tech-based strategies that improve customer convenience and experience.
4. Demonstrated the feasibility of coordinating services between multiple public and private providers.

According to a senior transportation official, *“The main purpose for implementing DCNC is to address equity issues, using technology to ensure reliability and flexibility, as well as improve access to critical resources – such as healthcare, food, government, and regional transportation options.”*

### **3.6 Conclusion**

Performance outcomes are impacted by operating costs, while on-time performance and ridership are heavily influenced by the level of service provided. Data also shows that trips within

the ODT zones that are less than 3 miles are frequent in DC.<sup>26</sup> This information can be helpful for other municipalities as they develop or expand their programs. ODT services are flexible and responsive, providing an alternative for riders who face long waits and transfers on traditional public transit. DCNC improves transit performance by giving first and last-mile connections and complements buses and trains. DCNC services address critical customer needs in ways that were not previously possible. Residents can easily access Metrorail and local points of interest, and the service helps to fill transit gaps and address equity issues in Ward 8.

DCNC services are replacing car journeys and transit excursions in the Northeast zones. On the other hand, ODT performance data indicates that further action is required to lower operational expenses and wait times. The agency's two customer satisfaction surveys from 2019 and 2022 show that riders want their on-time performance (wait time) to be sixteen minutes. However, wait times range from 25 to 30 minutes, posing a severe service reliability problem, particularly during busy service hours. The average cost of a passenger journey is what DCNC aims to achieve for operational costs. The data indicates that the service has only attained the lowest average cost per customer journey of \$16.70. The COVID-19 pandemic has impacted the ridership of DCNC's services, but it is gradually recovering. However, it is yet to reach pre-COVID levels.

## **Planning and Policy Considerations for ODT Implementation**

The key takeaways from the survey and interviews of local transit professionals show a strong need for performance-based planning for ODT services and a clear mechanism for tracking and aligning operations, planning, and policy goals. It is often assumed that implementing ODT and

---

<sup>26</sup> Foursquare ITP (2022, June 1). *Microtransit in DC Study*. Mwcog.org. Retrieved November 2, 2022, from [https://www.mwcog.org/assets/1/6/DC - TLC FY22 Microtransit in DC Final Report.pdf](https://www.mwcog.org/assets/1/6/DC_-_TLC_FY22_Microtransit_in_DC_Final_Report.pdf)

providing mobility options will solve the challenge of service gaps in areas without proper transit network connectivity. However, the lack of service design standards and criteria is a significant shortcoming of ODT adoption. Merely acquiring technology systems to implement ODT and provide transit options at riders' fingertips does not always solve the complex issues associated with transit service planning and service design. DFHV, for instance, has apparent goals and objectives for the DCNC service. The agency uses surveys as a feeder mechanism for learning about customer needs and expectations.

Effective monitoring and assessment of ODT performance outcomes are crucial to achieving policy objectives and goals, and planning and design should consider the demands of the community. Regular meetings to review ODT operational data against policy goals may be helpful. Another critical aspect of service design criteria is to ensure transparency and credibility in the planning and service design process. Riders and the public must believe that service offerings are based on a thorough analysis of service conditions. Without consistently valid information, people, especially transit-dependent riders, will not gravitate towards using a service they do not trust or believe will be available when needed.

In practice, transit agencies rely more on mobility service providers to perform background evaluations, such as market research and suitability analysis, before implementing ODT service. While this approach is an excellent first step in understanding market conditions, it is no substitute for a rigorous transit planning analysis, encompassing operational analysis, equity considerations, important service design and demographic factors, and Title VI challenges.

### **3.7 References**

Administration, F. T. (2020). Mobility Performance Metrics (MPM) for Integrated Mobility and Beyond  
Alonso-González, María J., Theo Liu, Oded Cats, Niels Van Oort, and Serge Hoogendoorn. 018. The  
potential of demand-responsive transport to complement public transport: An assessment framework and

- an empirical evaluation. *Transportation Research Record: Journal of the Transportation Research Board* 2672, 879-889. <https://doi.org/10.1177/0361198118790842>
- Alsaleh, N., & Farooq, B. (2023). Sustainability Analysis Framework for On-Demand Public Transit Systems. *arXiv preprint arXiv:2303.06007*.
- Ashour, L. A., & Shen, Q. (2022). Incorporating ride-sourcing services into paratransit for people with disabilities: Opportunities and barriers. *Transport Policy*, 126, 355–363.
- Babar, Y., & Burtch, G. (2020). Examining the heterogeneous impact of ride-hailing services on public transit use. *Information Systems Research*, 31(3), 820-834.
- Bardaka, E., Monast, K., Ghimire, S., Wang, J., Wright, J., & Scott, J. (2023, January). On-demand microtransit annual report - N.C. Department of Transportation. <https://www.ncdot.gov/divisions/integrated-mobility/public-transit-services/on-demand-microtransit/Documents/ncdot-on-demand-microtransit-annual-report.pdf>
- Barlish, K., & Sullivan, K. (2012). How to measure the benefits of BIM—A case study approach. *Automation In Construction*, 24, 149-159.
- Bates, J. W. (1986). Definition of practices for bus transit on-time performance: Preliminary study. *Transportation Research Circular*, (300)
- Begley, J. (2022, May 6). *Greater Washington's commuters continue to choose gridlock*. <https://www.brookings.edu/blog/the-avenue/2022/05/06/greater-washingtons-commuters-continue-to-choose-gridlock/>
- Bonner, T., & Miller-Hooks, E. (2023). Achieving equitable outcomes through optimal design in the development of microtransit zones. *Journal of Transport Geography*, 112, 103696.
- Braekers, K., Caris, A., & Janssens, G. K. (2014). Exact and meta-heuristic approach for a general heterogeneous dial-a-ride problem with multiple depots. *Transportation Research Part B: Methodological*, 67, 166-186.
- Brustein J (2016). Uber and Lyft want to replace public buses. URL <https://www.bloomberg.com/news/articles/2016-08-15/uber-and-lyft-want-to-replace-public-buses>.
- Bürstlein, J., López, D., & Farooq, B. (2021). Exploring first-mile on-demand transit solutions for North American suburbia: A case study of Markham, Canada. *Transportation Research Part A: Policy and Practice*, 153, 261-283.
- Casey, R. F., Labell, L. N., Moniz, L., Royal, J. W., Sheehan, M., Sheehan, T., ... & Parker, D. (2000). Advanced public transportation systems: The state-of-the-art update 2000.
- Center for Washington Area Studies (2023, September 20). *State of the Capital Region 2022: Commuting Patterns and Transportation Infrastructure*. <https://www.Centerforwashingtonareastudies.org/>. Retrieved October 8, 2023, from [https://www.centerforwashingtonareastudies.org/state\\_of\\_the\\_capital\\_region/2022/\\_book/Chapter2.html#figure-2.1-among-major-urban-areas-the-capital-region-is-second-only-to-new-york-in-its-reliance-on-public-transportation](https://www.centerforwashingtonareastudies.org/state_of_the_capital_region/2022/_book/Chapter2.html#figure-2.1-among-major-urban-areas-the-capital-region-is-second-only-to-new-york-in-its-reliance-on-public-transportation)
- Chakrabarti, S. (2022). Passively wait for gridlock or proactively invest in service. Strategies to promote car-to-transit switches among aspirational urbanites in rapidly developing contexts. *Transport Policy*, 115, 251-261.
- Chow, J. Y., & Sayarshad, H. R. (2016). Reference policies for non-myopic sequential network design and timing problems. *Networks and Spatial Economics*, 16, 1183-1209.
- Clewlou, R. R., & Mishra, G. S. (2017). Disruptive transportation: The adoption, utilization, and impacts of ride-hailing in the United States.
- Cordeau, J. F. (2006). A branch-and-cut algorithm for the dial-a-ride problem. *Operations Research*, 54(3), 573-586

- Dajani, J. S., & Gilbert, G. (1978). Measuring the performance of transit systems. *Transportation Planning and Technology*, 4(2), 97-103.
- Dillman, D. A. (1991). The design and administration of mail surveys. *Annual review of sociology*, 17(1), 225-249.
- District Department of Transportation (n.d.). *Mapping Transportation Needs*. Movedc.gov. Retrieved December 9, 2023, from <https://movedc.dc.gov/pages/mapping-transportation-needs>
- Dzisi, E. K. J., Obeng, D. A., Ackaah, W., & Tuffour, Y. A. (2022). MaaS for paratransit minibus taxis in developing countries: A review. *Travel Behaviour and Society*, 26, 18-27.
- Ellis, E. H., & McCollom, B. E. (2009). *Guidebook for rural demand-response transportation: measuring, assessing, and improving performance* (Vol. 36). Transportation Research Board.
- Erdoğan, S., Nohekhan, A., Shokputov, A., & Sadabadi, K. F. (2023). Multi-Criteria Decision-Making Framework for Determining Public Microtransit Service Zones. *Transportation Research Record*, 03611981231198464.
- Erhardt, G. D., Roy, S., Cooper, D., Sana, B., Chen, M., & Castiglione, J. (2019). Do transportation network companies decrease or increase congestion? *Science Advances*, 5(5), eaau2670.
- Erhardt, G. D., Hoque, J. M., Goyal, V., Berrebi, S., Brakewood, C., & Watkins, K. E. (2022).
- Errico, F., Crainic, T. G., Malucelli, F., & Nonato, M. (2013). A survey on planning semi-flexible transit systems: Methodological issues and a unifying framework. *Transportation Research Part C: Emerging Technologies*, 36, 324-338.
- Fan, Y., Zhang, Y., & Sun, R. (2019). Evaluating the Efficiency and Health Impacts of Next-Generation Transit System Design with Integration of Shared Mobility Services.
- Feagin, J. R., Orum, A. M., & Sjoberg, G. (Eds.). (2016). *A case for the case study*. UNC Press Books.
- Federal Transit Administration, U.S. [T.A.]. 020. "Mobility on Demand (MOD) Sandbox Program." July 16. <https://www.transit.dot.gov/research-innovation/mobility-demand-mod-sandbox-program>
- Feigon, S., and Murphy, C. (2016). Shared Mobility and the Transformation of Public Transit. TCRP Research Report 188. Transportation Research Board, Washington, D.C.
- Feigon, S., & Murphy, C. (2016). *Shared mobility and the transformation of public transit* (No. Project J-11, Task 21).
- Fielding, G. J., Babitsky, T. T., & Brenner, M. E. (1985). Performance evaluation for bus transit. *Transportation Research Part A: General*, 19(1), 73-82
- Furuhata, M., Dessouky, M., Ordóñez, F., Brunet, M. E., Wang, X., & Koenig, S. (2013). Ridesharing: The state-of-the-art and future directions. *Transportation Research Part B: Methodological*, 57, 28-46.
- Gan, A., Gui, F., & Tang, L. (2011). System for transit performance analysis using the national transit database. *Journal of Public Transportation*, 14(3), 87-107.
- GAO, A. (2012). *Paratransit Services: Demand Has Increased, but Little is Known about Compliance*. GAO-13-17, November.
- Gerring, J., & Seawright, J. (2008). Case selection techniques in case study research: A menu of qualitative and quantitative. *Political Research Quarterly*, 61(2), 294.
- Ghimire, S., Bardaka, E., Monast, K., Wang, J., & Wright, W. (2024). Policy, management, and operation practices in US microtransit systems. *Transport Policy*, 145, 259-278.
- Greater Washington Partnership (2018). Unlocking the Promise of Integrated Mobility in the Capital Region. [201807\\_GWP\\_Issue-Brief\\_Integrated-Mobility.pdf \(greaterwashingtonpartnership.com\)](https://www.greaterwashingtonpartnership.com/201807_GWP_Issue-Brief_Integrated-Mobility.pdf)
- Gill, P., Stewart, K., Treasure, E., & Chadwick, B. (2008). Methods of data collection in qualitative research: interviews and focus groups. *British Dental Journal*, 204(6), 291-295.
- Giuffrida, N., Le Pira, M., Inturri, G., Ignaccolo, M., Calabrò, G., Cuius, B., ... & Pluchino, A. (2020). On-demand flexible transit in fast-growing cities: The case of Dubai. *Sustainability*, 12(11), 4455.

- Glaser, B. G., & Strauss, A. M. (1967). *The discovery of grounded theory. Strategies for qualitative research.* New York: Aldine.
- Grabar H (2016). Cities are cutting public transportation because they think uber will fill the gap. They'll regret it. URL [http://www.slate.com/articles/business/metropolis/2016/12/cities\\_are\\_cutting\\_transportation\\_service\\_because\\_they\\_think\\_uber\\_will\\_fill.html](http://www.slate.com/articles/business/metropolis/2016/12/cities_are_cutting_transportation_service_because_they_think_uber_will_fill.html).
- Greenblatt, J. B., & Shaheen, S. (2015). Automated vehicles, on-demand mobility, and environmental impacts. *Current Sustainable/Renewable Energy Reports*, 2, 74-81.
- Guenther, R. P., & Hamat, K. (1988). *Distribution of bus transit on-time performance* (No. 1202).
- Gupta, D., Chen, H. W., Miller, L. A., & Surya, F. (2010). Improving the efficiency of demand-responsive paratransit services. *Transportation research part A: Policy and Practice*, 44(4), 201-217.
- Hall, J. D., Palsson, C., & Price, J. (2018). Is Uber a substitute or complement for public transit? *Journal of Urban Economics*, 108, 36-50
- Hands, D. W. (2010). Economics, psychology, and the history of consumer choice theory. *Cambridge Journal of Economics*, 34(4), 633-648
- Hassan, M. N., Hawas, Y. E., & Ahmed, K. (2013). A multi-dimensional framework for evaluating the transit service performance. *Transportation Research Part A: Policy and Practice*, 50, 47-61.
- Hansen, T., Walk, M., Tan, S., & Mahmoudzadeh, A. (2021). Performance Measurement and Evaluation Framework of Public Microtransit Service. *Transportation Research Record*, 2675(12), 201-213.
- Hazan, J. (2021, January 8). *On-Demand Transit Can Unlock Urban Mobility*. <https://www.bcg.com/publications/2019/on-demand-transit-can-unlock-urban-mobility>
- Hazan, J., Lang, N., Wegscheider, A. K., & Fassenot, B. (2019). On-demand transit can unlock urban mobility. *BCG Henderson Institute and Boston Consulting Group*.
- Hong, S., Oxley, L., & McCann, P. (2012). A survey of the innovation surveys. *Journal of Economic Surveys*, 26(3), 420-444.
- Inturri, G., Le Pira, M., Giuffrida, N., Ignaccolo, M., Pluchino, A., Rapisarda, A., & D'Angelo, R. (2019). Multi-agent simulation for planning and designing new shared mobility services. *Research in Transportation Economics*, 73, 34-44.
- Jung, P. H., Kim, H., Lee, K., & Song, Y. (2022). Examining Day-to-Day Dynamic Transit Accessibility Using Functional Data Analysis. *The Professional Geographer*, 74(3), 503-515.
- Kane, J.A., Tomer, A., and Puentes, R. (2016). *How Lyft and Uber Can Improve Transit Agency Budgets*. Report. Brookings Institution. Available from <https://www.brookings.edu/research/how-lyft-and-uber-can-improve-transit-agencybudgets/>
- Kaufman, S. M., Smith, A., O'Connell, J., & Marulli, D. (2016). *Intelligent paratransit*.
- Koffman, D. (2004). *Operational Experiences with Flexible Transit Services*. Vol. 53 of TCRP Synthesis Report. Transportation Research Board.
- Le Pira, M., Marcucci, E., Gatta, V., Inturri, G., Ignaccolo, M., & Pluchino, A. (2017). Integrating discrete choice models and agent-based models for ex-ante evaluation of stakeholder policy acceptability in urban freight transport. *Research in Transportation Economics*, 64, 13-25.
- Lucken, E., Frick, K. T., & Shaheen, S. A. (2019). "Three Ps in a MOD:" Role for mobility on demand (MOD) public-private partnerships in public transit provision. *Research in Transportation Business & Management*, 32, 100433
- Ma, T. Y. (2017, June). On-demand dynamic Bi-/multi-modal ridesharing using optimal passenger-vehicle assignments. In *2017, the IEEE International Conference on Environment and Electrical Engineering and 2017 IEEE Industrial and Commercial Power Systems Europe (EEEIC/I&CPS Europe)* (pp. -5). IEEE.

- Martinez, L. M., & Viegas, J. M. (2017). Assessing the impacts of deploying a shared self-driving urban mobility system: An agent-based model applied to the city of Lisbon, Portugal. *International Journal of Transportation Science and Technology*, 6(1), 13-27.
- Matherly, D. (1997). Developing a performance-based transit allocation formula: Case study for a participatory process. *Transportation Research Record*, 1604(1), 83-91.
- McFadden, D. (2010a). "Disaggregate Behavioral Travel Demand's RUM Side – A 30 Year Retrospective," in *Travel Behavior Research*, ed D. A. Hensher (Amsterdam: Elsevier), 17–63.
- Metropolitan Washington Council of Governments (2023, April 12). *COG presents first major update to regional growth forecasts since COVID*. <https://www.Mwcog.org/>. Retrieved October 4, 2023, from <https://www.mwcog.org/newsroom/2023/04/12/cog-presents-first-major-update-to-regional-growth-forecasts-since-covid-cooperative-forecast/#:~:text=The%20region%20is%20currently%20home,over%20the%20next%20three%20decades>
- Miah, M. M., Naz, F., Hyun, K. K., Mattingly, S. P., Cronley, C., & Fields, N. (2020). Barriers and opportunities for paratransit users to adopt on-demand micro transit. *Research in Transportation Economics*, 84, 101001.
- Montgomery County Department of Transportation (2022, September 6). *Montgomery County Executive Regulation*. [montgomerycountymd.gov](https://www.montgomerycountymd.gov). Retrieved December 9, 2023, from <https://www.montgomerycountymd.gov/exec/Resources/Files/15-22T.pdf>
- Morris, J. M., Dumble, P. L., & Wigan, M. R. (1979). Accessibility indicators for transport planning. *Transportation Research Part A: General*, 13(2), 91–109.
- Mouter, N. (2021). *New Methods, reflections, and application domains in transport appraisal*. Academic Press
- Mulley, C., & Nelson, J. D. (2009). Flexible transport services: A new market opportunity for public transport. *Research in Transportation Economics*, 25(1), 39–45.
- Muro-Rodríguez, A. I., Perez-Jiménez, I. R., & Gutiérrez-Broncano, S. (2017). Consumer behavior in the choice of mode of transport: a case study in the Toledo-Madrid corridor. *Frontiers in Psychology*, 8, 1011.
- National Center for Applied Transit Technology (2020, March 31). *Innovative Technology Strike Team Technical Assistance - Midwestern Group of 6 Counties*. Transit Center. Retrieved October 8, 2023, from <https://n-catt.org/wp-content/uploads/2022/05/20220331-N-CATT-Dispatch-GENERIC-Final-Recommendations-Report-v1.1.pdf>
- O'Brien, K. K., Colquhoun, H., Levac, D., Baxter, L., Tricco, A. C., Straus, S., ... & O'Malley, L. (2016). Advancing scoping study methodology: a web-based survey and consultation of perceptions on terminology, definition, and methodological steps. *BMC health services research*, 16, 1-12.
- Palmer, K., Dessouky, M., & Abdelmaguid, T. (2004). Impacts of management practices and advanced technologies on demand responsive transit systems. *Transportation Research Part A: Policy and Practice*, 38(7), 495-509.
- Patel, R. K., Etmiani-Ghasrodashti, R., Kermanshachi, S., Rosenberger, J. M., & Foss, A. (2022). Mobility-on-demand (MOD) Projects: A study of the best practices adopted in United States. *Transportation Research Interdisciplinary Perspectives*, 14, 100601.
- Pinto, J., Santos, M. C., & Matos, P. V. (2021). Contracting out public transit services: an incentive performance-based approach.
- Qiu, F., Li, W., & Haghani, A. (2015). A methodology for choosing between fixed-route and flex-route policies for transit services. *Journal of Advanced Transportation*, 49(3), 496-509.

- Rayle, L., Shaheen, S., Chan, N., Dai, D., & Cervero, R. (2014). App-based, on-demand ride services: Comparing taxi and ridesourcing trips and user characteristics in San Francisco university of California Transportation Center (UCTC). *University of California, Berkeley, United States*, 2, 49-52.
- Rodman, W., High, W., (2 18). ADA Paratransit Service Models: A Synthesis of Practice. TCRP Synthesis 135. Transportation Research Board, Washington, D.C., 2007.
- Ross, S. M. (2 17). *Introductory statistics*. Academic Press.
- Rossetti, T., Broaddus, A., Ruhl, M., & Daziano, R. (2023). Commuter preferences for a first-mile/last-mile microtransit service in the United States. *Transportation Research Part A: Policy and Practice*, 167, 103549.
- Sanaullah, I., Alsaleh, N., Djavadian, S., & Farooq, B. (2021). Spatio-temporal analysis of on-demand transit: A case study of Belleville, Canada. *Transportation Research Part A: Policy and Practice*, 145, 284-301.
- Shaheen, S., Cohen, A., Chan, N., & Bansal, A. (2020). Sharing strategies: carsharing, shared micromobility (bikesharing and scooter sharing), transportation network companies, microtransit, and other innovative mobility modes. In *Transportation, land use, and environmental planning* (pp. 237-262). Elsevier.
- Shaheen, S., & Chan, N. (2016). Mobility and the sharing economy: Potential to facilitate the first-and last-mile public transit connections. *Built Environment*, 42(4), 573-588.
- Shaheen, S., Cohen, A., Yelchuru, B., Sarkhili, S., & Hamilton, B. A. (2017). Mobility on demand operational concept report.
- Shaheen, S., Cohen, A., & Zohdy, I. (2 16). *Shared mobility: current practices and guiding principles* (No. FHWA-HOP-16- 22). United States. Federal Highway Administration.
- Smith, A. (2 17). Record shares of Americans now own smartphones, have home broadband.
- Sisson, P. (2018, January 9). *Microtransit: How cities are, and aren't, adapting transit technology*. Cu bed. <https://archive.curbed.com/2018/1/9/16871474/microtransit-mass-transit-uber-lyft>
- Steiner, R. L., Srinivasan, S., Mohebbi, M. M., Patni, S., Suarez, J., Krinos, L., & Rummler, J. (2021). Evaluation of East Gainesville's Microtransit Mobility Project.
- Strathman, J. G., & Hopper, J. R. (1993). Empirical analysis of bus transit on-time performance. *Transportation Research Part A: Policy and Practice*, 27(2), 93-100.
- Sweet, M. N., & Scott, D. M. (2 21). Shared mobility adoption from 2016 to 2018 in the Greater Toronto and Hamilton Area: Demographic or geographic diffusion?. *Journal of Transport Geography*, 96, 103197.
- Thaler, R. (1980). Toward a positive theory of consumer choice. *Journal of Economic Behavior & Organization*, 1(1), 39-60.
- Thatcher, R., Gaffney, J. K., & Dynatrend, E. G. (1991). *ADA paratransit handbook: Implementing the complementary paratransit service requirements of the Americans with Disabilities Act of 1990* (No. UMTA-MA-06-0206-9 -1). United States. Urban Mass Transportation Administration.
- Todd Litman, "When Are Bus Lanes Warranted?" Victoria Transport Policy Institute, November 25, 2016, p. 4, <http://www.vtpi.org/blw> pdf. While this is the general trend, not every route will experience the same amount of ridership growth.
- TransitCenter, "Private Mobility, Public Interest: How Public Agencies can Work with Emerging Mobility Providers," 2016.
- Transit Center (n.d.). *The Washington D.C. Story*. Retrieved October 8, 2023, from <https://dashboard.transitcenter.org/story/dc>
- Transportation Planning Board (2018, April 6). *Transportation Network Companies (TNCs) in the Washington Region*. Mwcog.org. Retrieved December 9, 2023, from [https://www.mwcog.org/assets/1/28/04062018 - Item 2 - Transportation Network Companies \(TNCs\) in the Region.pdf](https://www.mwcog.org/assets/1/28/04062018_-_Item_2_-_Transportation_Network_Companies_(TNCs)_in_the_Region.pdf)

- Van Lierop, D., & El-Geneidy, A. (2016). Enjoying loyalty: The relationship between service quality, customer satisfaction, and behavioral intentions in public transit. *Research in Transportation Economics*, 59, 50-59.
- Veuger, S., Begley, J., Brooks, L., McCabe, B. J., & Scheutz, J. (2022). State of the Capital Region 2022: Commuting Patterns and Transportation Infrastructure.
- Wang, S., Correia, G. H. D. A., & Lin, H. X. (2019). Exploring the performance of different on-demand transit services provided by a fleet of shared automated vehicles: An agent-based model. *Journal of Advanced Transportation*, 2019, 1-16.
- Weckström, C., & Mladenović, M. N. (2020). Evaluation of public transport policy formulation and implementation: Case study of 24 mid-sized Nordic cities. *Transportation Research Procedia*, 45, 979-986.
- Weinreich, D. P., Reeves, S. M., Sakalker, A., & Hamidi, S. (2020). Transit in flex: Examining service fragmentation of app-based, on-demand transit services in Texas. *Transportation Research Interdisciplinary Perspectives*, 5, 100060.
- Weinreich, D., Skuzinski, T., & Hamidi, S. (2018). Overcoming Local Barriers to Regional Transportation: Understanding Transit System Fragmentation from an Institutional Framework [Policy Brief].
- Westervelt, M., Huang, E., Schank, J., Borgman, N., Fuhrer, T., Peppard, C., & Narula-Woods, R. (2018). UpRouted: Exploring Microtransit in the United States.
- Wilbur, M., Ayman, A., Sivagnanam, A., Ouyang, A., Poon, V., Kabir, R., ... & Dubey, A. (2023). Impact of COVID-19 on public transit accessibility and ridership. *Transportation Research Record*, 2677(4), 531-546
- Yao, D., Xu, L., & Li, J. (2019). Evaluating the performance of public transit systems: A case study of eleven cities in China. *Sustainability*, 11(13), 3555.
- Zhang, C., Juan, Z., Luo, Q., & Xiao, G. (2016). Performance evaluation of public transit systems using a combined evaluation method. *Transport Policy*, 45, 156-167.

# **4 A Multi-Attribute Decision-Making Approach to Measuring Microtransit Accessibility**

## **Abstract**

This paper presents a multi-attribute decision-making (MADM) approach to planning accessible microtransit services. Measuring ease of access to microtransit services is crucial in evaluating and allocating resources. However, decision-making regarding microtransit accessibility and adoption is often uncertain due to a lack of data and poor planning approaches for measuring microtransit accessibility. MADM is a method based on multi-attribute utility theory. It can include a broad range of quantitative and qualitative accessibility attributes that can be incorporated into the decision-making process. A composite index approach is proposed in this paper that combines the microtransit propensity index, a level of service measure, and a weighted average score for individual accessibility measures. The paper reviews previous and current accessibility methods and applies the MADAM composite index approach to a case study of microtransit services in Prince George's and Montgomery Counties in Maryland. A questionnaire and interviews were used to gather vital information from transit planners and practitioners, such as service span, service area, service type, and service performance data. This data provides essential information to inform planning and decision-making regarding microtransit accessibility at the strategic, tactical, and operational levels. This paper reveals how the MADAM approach can potentially enhance the design and planning of microtransit services to enhance accessibility.

## 4.1 Introduction

In recent decades, transportation professionals have relied on traditional optimization models to support decision-making. This includes applying advanced optimization modeling tools and analysis techniques such as Geographic Information Systems (GIS), Intelligent Transportation Systems (ITS), Planning Support Systems (PSS), Expert Systems (ES), Artificial Intelligence (AI), and Optimization Algorithms (OA) (Fischer & Getis, 2010; Dey, 2001; Shim et al., 2002). For public transportation, municipalities and transit agencies have used ridership-based evaluation methods for decision-making, which gauge the success of transportation systems through ridership metrics. However, these methods only sometimes account for situations where high ridership is due to a lack of choice and do not directly capture the usefulness of services (Merlin et al., 2021).

Since these models were initially developed in the 1970s, quantitative and spatial optimization modeling has become a potent tool for addressing transportation planning issues. However, newer technologies have added more uncertainty to transportation planning and decision-making. Some aspects of accessibility and the competitiveness of current transportation systems are frequently overlooked by modeling methods (Kramer & Goldstein, 2015; Fayyaz et al., 2017). According to June et al. (2022), transportation networks are dynamic and vulnerable to temporal changes in accessibility. In addition to supporting planning, legislation, and system assessment, transit accessibility measures should consider network interconnections and identify the requirements of underserved populations (June et al., 2022; Zhang et al., 2018). Multi-attribute decision-making (MADM), which is based on a composite index to assess accessibility of microtransit accessibility, is one analytical method that can take these measures into account.

A critical aspect of planning microtransit services is crucial to understanding current disparities in access to opportunities such as jobs by transit.<sup>27</sup> Handley, Fu, and Tupper (2019) suggested adopting comprehensive connectivity measures to account for designed accessibility as a function of space and time across the transportation analysis zones. However, such complex tools are missing from many existing quantitative and spatial analysis methods because they need context-based considerations, especially when they do not include additional attributes to achieve efficient and timely delivery of microtransit services.

Allocating resources for microtransit and its service attributes is challenging due to operational, financial, and institutional barriers (He & Ma, 2022). Traditional decision-making techniques must be improved to provide accurate information on critical issues concerning microtransit service attributes and preferences (He & Ma, 2022). The lack of accurate and readily available data has led to ad-hoc methodologies for microtransit planning and service design. These methodologies often focus too much on linking population and employment intensities to zonal attributes without a systematic process to assess accessibility in decision-making. This issue has been pointed out by He and Ma (2022) and Hawas et al. (2016). The MADM approach presents a valuable decision-making tool for microtransit (Deng et al., 2021; Al & Lownes, 2011). This approach can be utilized to analyze the factors affecting microtransit accessibility and support service design (Alterman, 1988; Aman & Smith-Colin, 2020; He & Ma, 2022). Using multiple criteria for decision-making provides a comprehensive approach to evaluating microtransit accessibility, incorporating the perspectives of users and planners.

Studies have recently emerged that delve into new methodologies and evidence for analyzing mobility and the social inequalities that arise from transportation policy and decision-making. This

---

<sup>27</sup> Transit Center (2022, December 19). *Exploring 2022's Big Transit Themes with New Equity Dashboard Data: Part One*. Transitcenter.org. Retrieved October 5, 2023, from <https://transitcenter.org/exploring-2022s-big-transit-themes-with-new-equity-dashboard-data/>

approach tackles the uncertainty that often occurs during planning and involves using readily available methods and data. It addresses vital dimensions of microtransit, including evaluating expected accessibility outcomes and service attributes (He & Ma, 2022). There are many approaches for combining information from different data (Lee et al., 2016). Previous work by Al Mamun et al. (2011) and Deng et al. (2021) have emphasized three primary accessibility components: spatial and temporal coverage. This study also draws upon works by Alterman (1988), Lee et al. (2016), He and Ma (2022), Mokhtarian (2011), and Sevgi et al. (2023) that examined multi-attribute decision-making frameworks considering numerous factors like the quality of service, ridership, population, zonal characteristics, and other socio-economic attributes all at once. This study examines microtransit accessibility factors and their relationships with decisions to adopt microtransit using a case study approach in Prince George's and Montgomery Counties in Maryland.

This study assumes microtransit accessibility is related to connectivity, a combination of factors connected to mode captivity and mode choice (Beimborn et al., 2003; Handley et al., 2019). Better decisions can be made for microtransit outcomes by considering accessibility and connectivity measures (Beimborn et al., 2003). Microtransit solves accessibility and connectivity issues, and the decision problems associated with microtransit involve geographical elements from a set of feasible alternatives and multiple conflicting dealings with different evaluation criteria, as identified by Drobne and Lisec (2009). Microtransit accessibility and connectivity are spatial problems that lead to multi-attribute decision-making (MADM) based on geographical selection and coverage issues, such as ease of access and proximity (Drobne & Lisec, 2009). It is essential to consider the selection of microtransit zones or service locations from alternative locations as a multiple-criteria decision-making problem (Mokhtarian, 2011).

It's crucial to comprehend the way microtransit service design affects accessibility. This research provides methodological insights for planning and policy analysis from microtransit and accessibility studies, contributing to current debates regarding transport accessibility and social equity. Transit agencies can benefit from this study by using a comprehensive, versatile, and sturdy decision-making framework to identify areas with high potential for successful and accessible microtransit deployment. This study shows the impact of accessibility on microtransit decision-making, which can improve accessibility to jobs, especially for low-income individuals, while bridging the inequality gap in public transit infrastructure and policies.

## **4.2 Purpose and Objectives**

This paper describes a composite method for quantifying microtransit access that combines existing accessibility components and decision-making. It introduces a multi-attribute decision-making approach to measure microtransit accessibility. Its main objectives are: (1) to address gaps in the literature by presenting a consistent framework to assess microtransit accessibility; (2) to explore the adoption of microtransit services using multi-attribute decision-making methods to measure accessibility; (3) to understand the need for improvement in the microtransit systems; and (4) summarize the research on microtransit accessibility, including the concept of accessibility, multi-attribute decision-making methods, level of service in the context of demand response for microtransit, and the weighted average scores. This comprehensive approach is essential in addressing uncertainty in planning and decision-making. The study seeks to illustrate the relationships between various accessibility attributes and provides a straightforward approach to weighing the attributes. This study contributes to the literature by measuring microtransit accessibility and assessing key attributes to consider when evaluating microtransit service outcomes.

This chapter proceeds with a literature review of existing transportation accessibility measures, highlighting applicable concepts and measures relating to microtransit accessibility and planning decision-making. Next, the study methodology is presented. The methodology section emphasizes the three approaches in framing multi-attribute decision-making (MADM). A discussion of the case study follows this. The results section offers a comparative analysis using a composite measure output from the MADM approach. The section discusses the case study results from PGC Link in Prince George's County and Ride On Flex in Montgomery County, Maryland. The last section concludes the paper with a summary of significant findings and a discussion of how the proposed MADM approach can improve the planning of accessible microtransit.

### **4.3 Literature Review**

Municipalities and transit agencies have recently launched microtransit services that offer fixed routes, scheduled operations, and more flexible routes and on-demand scheduling. Microtransit is a technology-enabled shared transportation mode that combines flexible routing, on-demand, shared rides, and traditional fixed-route transit forms of mobility. Microtransit as a technology is powered by real-time dynamic dispatching and scheduling systems. These dynamic routing and information technology systems use advanced digital technology innovations and platforms that employ algorithms to direct vehicles (including navigation tools, ride-sharing apps, delivery and ride services, and autonomous vehicles). These systems are embedded with elements in an interoperable value chain, with elements shared by users and businesses (Zayat et al., 2023).

Microtransit has the potential to improve efficiency and reduce costs by allowing transit agencies and riders to share rides in high-capacity vehicles and vans. Microtransit can offer better service and more comfortable rides with real-time dynamic dispatching and scheduling technology. Transit accessibility, as applied to microtransit, further captures the ability of transit agencies to

connect riders effectively and efficiently from their points of origin to their destination within reasonable travel times (Murray, 2003; KFH Group. 2013). However, the rapid evolution of microtransit technologies has resulted in more alternatives for businesses. With accessibility being a key factor in the planning and decision-making process on microtransit adoption, the decision-making process is a non-trivial problem and requires complex control subsystems. The deployment of microtransit services involves an analysis of potential service zones and operational needs (Acheampong et al., 2020; Rossetti et al., 2023). Selecting the appropriate method for the decision-making process is essential. Only some methods can be used to solve multiple types of decision-making problems. Applying an unsuitable method can lead to inaccurate decisions, which results in spending much money on adapting technologies (Zayat et al., 2023; Aruldoss et al., 2013; Saaty, 2008).

With new advancements in information and telecommunications technologies, constantly evolving travel behaviors, and evolving community needs, policymakers and transit agencies must continually examine transportation planning approaches, including the service design process for microtransit and how different strategies of microtransit deployment have addressed accessibility challenges. Schwieterman et al. (2018) have identified the absence of well-defined methodologies for evaluating microtransit accessibility as barriers to further developing and adopting these services. Without a framework to make and assess decisions, efforts to improve transportation choices and enhance accessibility will be hampered by a lack of practical planning tools. This research, therefore, proposes a multi-attribute decision-making method (MADM) for exploring the question of microtransit accessibility.

The research examines microtransit accessibility by utilizing a multi-attribute decision-making framework, a composite framework with measures to rank elements. MADM is part of

multiple criteria, known as a multi-disciplinary approach, framework, and methodology (Zolfani et al., 2016). This study involves three assessment techniques, including the Microtransit Propensity Index (MPI), Level of Service (LOS), and Weighted Average Score (WAS) (Sevgi et al., 2023; Akincilar & Dagdeviren, 2014). Details about these methods are discussed in the Methods section.

### ***Multi-Attribute Decision-Making (MADM)***

The MADM methods are systematic approaches that support decision-making processes. In recent years, several studies have pointed to the benefits of utilizing multi-attribute and mixed evaluation methods to support transit planning and improve decision-making tools and models (Merlin, Singer & Levine, 2021; Ma et al., 2019; Martinez & Viegas, 2017; Alonso-González et al., 2018). These techniques are commonly used in various decision-making problems related to planning. The literature on this topic has not yet utilized the MADM framework despite the availability of various other approaches and measures. According to Zayat et al. (2023), there are many MADM methods, each with distinct characteristics. Each method has advantages and disadvantages, and different results can be obtained by applying various methods (Zardari et al., 2014; Zayat et al., 2023; Aruldoss et al., 2013; Saaty, 2008). The application of MADM in transit planning must be contextualized because some methods may only sometimes consider situations where high ridership is due to a lack of choice and may not directly reflect the service's utility (Merlin et al., 2021). Hence, policymakers and planning practitioners must ensure that microtransit services are designed to maximize performance outcomes and benefits, align with local priorities, and improve residents' quality of life (Bouton et al., 2017). Microtransit has been widely adopted in various forms, significantly transforming the transit sector technologically. However, the performance of the technologies associated with microtransit accessibility is still being determined due to the different contexts of applications. Hence, policymakers and planning practitioners must

ensure that microtransit services maximize ease of access and connections to places of interest, align with local priorities, and improve residents' quality of life (Bouton et al., 2017). To achieve this, practitioners and decision-makers must identify, examine, assess, and select alternatives. Transit agencies and municipalities face the challenge of evaluating and selecting options based on conflicting attributes and criteria.

In this research, a weighting process is used to determine the significance of evaluation criteria and performance indicators that are gathered and dispensed by the Federal Transit Administration (FTA) through the National Transit Database (NTD) (Gan et al., 2011; Baratian-Ghorghi et al., 2017). "importance" refers to a transportation professional or stakeholder's perceived value of the criterion or performance indicator. However, different stakeholders may have different biased opinions towards specific criteria. Therefore, a composite framework and technique that reduces bias in the weighting process is essential.

Measuring and assessing accessibility is a crucial element in enhancing transportation equity. It is essential to calculate and determine the accessibility of microtransit based on its spatial coverage or availability within the defined service area and the ability of individuals to use the system (Aman et al., 2021). To address these increasingly critical issues, transit studies related to microtransit design, system assessment, service performance evaluation, and transit planning efforts require accurate microtransit accessibility measurements (Malekzadeh & Chung 2020).

For this paper, a MADM is described and presented as a framework for evaluating microtransit accessibility, which also applies to the planning and expansion of microtransit services. In addition to the design of microtransit service zones, such as establishing boundaries, service stops, and fares, it is assumed that transit agencies and municipalities should ensure service accessibility based on a predefined reliability level, service quality, and cost performance. This study examines

the accessibility of microtransit services to jobs and how it impacts the decision to adopt microtransit.

### ***Microtransit Propensity Index (MPI)***

The Microtransit Propensity Index (MPI) is an invaluable tool used to evaluate the viability of microtransit services. It considers socioeconomic factors that suggest a higher likelihood of using on-demand services. It identifies populations and jobs that rely heavily on public transportation and who need to make frequent daily trips outside peak hours. Additionally, the MPI assesses the likelihood of connecting to fixed route networks by microtransit and measures the impact of demographic and population attributes. A score is calculated for each Census Block Group located within the microtransit zone. The MPI has been successfully implemented in several microtransit studies, including Ride On Flex in Montgomery County, PGC Link Microtransit in Prince George's County, and DC Neighborhood Connect (Erdoğan et al., 2023; Bonner et al., 2023).

### ***Level of Service (LOS)***

The Level of Service (LOS) method uses Transit Capacity to evaluate demand-responsive transit. The Quality of Service Manual (TCQSM) provides a comprehensive framework that includes response time, service span, availability, coverage, reliability, on-time performance, trips not served, and travel time to support planning and decision-making (Quade, 2003; Godavarthy et al., 2015). The Federal Transit Administration (FTA) requires the level of service for demand-responsive services for people with disabilities to include service characteristics such as the hours and days of service, response time, etc.<sup>28</sup> The TCQSM also outlines the parameters required to measure

---

<sup>28</sup> Federal Transit Administration (n.d.). *What Are the Requirements for Demand-Responsive Service?* [Www.Transit.dot.gov/](https://www.transit.dot.gov/what-are-requirements-demand-responsive-service). Retrieved September 11, 2022, from <https://www.transit.dot.gov/what-are-requirements-demand-responsive-service>

microtransit accessibility and availability, such as service span, travel time, and service coverage (Godavarthy et al., 2015; Danaher, 2000; KFH Group, 2013). The highest level of service for demand response transit, according to the TCQSM, is sixteen or more hours per day, which extends into mid-evening hours (Table 25). Travel time is a crucial factor in determining the feasibility of transit use (Polzin et al., 2002). However, not all service attributes are equally important, and it is difficult to define the relative importance of those attributes for which LOS values are proposed (Botzow, 1974). The level of service frequently changes between peak and off-peak hours, affecting headways, frequency, and trip/travel duration that depend on the average configured speed on vehicle and app and roadway conditions (Botzow, 1974).

### ***Weighted Average Scores (WAS) Method***

The Weighted Average Score (WAS) is a commonly used method to calculate an average where specific data points are more important than others. This method is beneficial for determining order preferences by weight, allowing a score or more to be assigned a greater significance or weight. This helps identify the appropriate transit service accessibility factors based on set attributes and values. The weighted average is found by multiplying each number by weight and then adding the results (Lee et al., 2016; He and Ma, 2022; Mokhtarian, 2011; Sevgi et al., 2023). WAS is an analytical hierarchy process (AHP) approach that complements systematic planning and analysis for developing multicriteria decision techniques (Saaty, 1980). It involves using multiple attributes to evaluate and rank decision attributes based on decision preferences (Zahedi & Kılıçman, 2019; Sevgi et al., 2022). Weighted Average Score (WAS) is found by averaging scores, and the weight score is determined by a set of pairwise comparisons using a matrix format (Sevgi et al., 2022).

### ***Microtransit Accessibility Concept***

As discussed in the previous chapters, microtransit has emerged as a flexible solution for filling gaps in transit coverage by connecting people to employment and essential services, especially in underserved communities, low densities areas, and transit-dependent populations (Shaheen et al., 2016a; Steiner et al., 2021). Unlike traditional transit, microtransit is flexible and can offer point-to-point transit in various ride-sharing configurations. Shaheen and Cohen (2018) state that on-demand transit services like microtransit are increasingly crucial in urban mobility. As microtransit continues to evolve and its adoption accelerates, more research is needed on potential issues surrounding microtransit accessibility and the different perspectives on accessibility and decision-making approaches (Alterman, 1988; Dey, 2001; He & Ma, 2022; Fischer & Getis, 2010; Shim et al., 2002; Hawas et al., 2016).

The concept of accessibility is not new to transit. According to Bree et al. (2020), accessibility is commonly used but often not defined or measured consistently. Handy and Niemeier (1997) described local accessibility as the ease with which residents can reach critical points of interest within their neighborhoods, such as a local grocery or drugstore—measured by walkability factors, such as intersection density, the length of the walking path, and street connectivity (Wu et al., 2023). Prior research has focused on defining and building the concept of transit accessibility based on experiences in paratransit and fixed-route bus and train services (Acheampong et al., 2020; Aman et al., 2020; Rossetti et al., 2023). Accessible transit options like microtransit are indispensable for everyone, especially those in vulnerable situations (Buenk et al., 2019). However, ensuring the accessibility of transit systems has always been a crucial yet challenging task for transportation researchers and transit agencies, especially in the context of microtransit. Current literature on microtransit has concentrated on the operational and technological aspects of microtransit, i.e., the application of new technologies with limited research on accessibility and its relationship to planning decision-making processes. The connectivity of services within microtransit

zones or to the core transit network is a key benefit of microtransit. However, the relationship between connectivity and accessibility is often not defined in microtransit studies. The design of microtransit services is crucial to improving transit distribution and addressing coverage and equity challenges. Some researchers have suggested linking these elements because microtransit services can induce new trips and complement fixed route services by addressing the first and last-mile problems in transit (Acheampong et al., 2020). However, it is unclear how the existing transit accessibility measures relate to microtransit (Bree et al., 2020). These issues are worth exploring in future studies.

### ***Measuring Microtransit Accessibility in Planning Setting***

Compared to traditional transportation planning and decision-making approaches, multi-attribute decision-making and adaptive planning can improve decision support systems for transit, which involve human experts such as planners and policymakers. Disaggregated transit accessibility measurements are becoming more popular (Malekzadeh & Chung, 2020). For instance, Wei et al. (2018) argue that the need for a unified approach makes it difficult for planners to assess transit service performance comprehensively. This could lead to suboptimal decision-making in service planning and operation. Several studies have indicated a spatial mismatch between the distribution of transit-dependent populations, public transit provision, and employment distributions in many cities, including the Prince George's and Montgomery Counties in Maryland and the Washington D.C. region. Therefore, there is limited data on how accessibility is measured, assessed, and monitored for microtransit services. This study explores accessibility to jobs via microtransit and how this affects decision-making regarding adopting microtransit.

### ***Benefits of Microtransit Adoption***

Understanding what transit agencies want to accomplish and why it is essential for microtransit implementation is necessary. Increasing choice and accessibility are prioritized when expanding transportation connections/options to allow diverse communities to access opportunities. Studies have identified five key policy goals for adopting microtransit, as outlined in Table 14.

*Table 14 Microtransit Choice and Accessibility Goals and Priorities*

<b>Goals/Expectations</b>	<b>Description</b>
<b>Increase first- and last-mile connections and improve access</b>	Enhance connections and accessibility to critical resources such as healthcare, food, government, etc. Address the needs of disadvantaged populations such as seniors, riders with disabilities, low-income, and no-vehicle households.
<b>Invest in technologies that optimize transit operations, costs, and long-term capital investment.</b>	Optimize transit operating costs by minimizing long-term capital investment or risk. Apply enhanced technologies to improve communications, on-demand, and real-time information.
<b>Enhance the customer experience and satisfaction.</b>	Faster average trip, reduce wait-time and travel time. Provide more trips within 45 minutes from point A to point B.
<b>Increase access to jobs and educational centers with non-auto options</b>	Deliver a system that improves access to opportunities and quality of life. Expand access to fixed route transit network to connect to employment centers. Quick connections to key destinations like grocery stores, especially on weekends.
<b>Provide alternative transit options.</b>	Provide transit alternatives and deliver a higher quality of service for a comparable cost to today’s fixed route. Consider the mobility and transportation needs of underserved and overburdened communities in project selection and scoping.
<b>Increase transit ridership</b>	Grow ridership with a convenient and tech-enabled experience that includes curb-to-curb pickups and drop-offs for mobility-limited riders.

Many transit agencies and local municipalities, including practitioners and decision-makers, are challenged with developing the most effective strategies to provide accessible and integrated transit services while achieving a range of public policy objectives (May 1991). Municipalities, transit agencies, and mobility providers such as transport network companies now offer a spectrum of microtransit services. Microtransit has emerged as a promising accessible transportation solution for filling gaps in transit coverage and connecting populations to employment and essential services (Shaheen, Cohen, & Zohdy, 2016a). However, because of the intricate and unique nature of each city or region, adopting microtransit can be complicated and challenging at times (He & Ma, 2022). The varying planning capabilities between public transit agencies and local government entities means

the transition will play out differently and produce different results among cities (Bouton et al., 2017). The challenge is that the planning and provision of public transit systems is complex and can be contentious (Fischer, Ray, & King, 2020); *The Incremental Model of Decision Making*, 2017; Lindblom, C. E. (1959).

Numerous studies have emphasized decision-making for transportation operations to evaluate transit systems as a whole or in part. Accessibility is widely discussed in the literature but not often translated into performance measures that assess policies (Handy & Niemeier, 1997). Also, research on the quantitative evaluation of microtransit accessibility based on a multi-attribute decision-making approach has been scarce. Transit riders consider accessibility a key factor when choosing public transit (Kerrigan & Bull, 1992). Substantial gaps and critical deficits exist in existing knowledge of transportation governance, planning processes, and policy outcomes (Fisher et al., 2020).

Research indicates significant gaps in access for individuals on wheelchairs or mobility aids due to a lack of investment in ADA-compliant infrastructures such as vehicles, bus stops, transit stations, sidewalks, crosswalks, etc. (Kauffman et al. 2016; GAO 2012). The accessibility of microtransit services plays a significant role in users' mode choices (Fayyaz et al., 2017; Merlin et al., 2021; Moniruzzaman and Páez, 2012). Therefore, accessibility performance measures should be an integral part of the decision-making process, including coverage, level of service, network design, system operations, and population demographics (LaMondia et al., 2010; Iacono et al., 2010). However, data on access for people with disabilities is unavailable or incomplete. The lack of such information makes it difficult for practitioners and decision-makers to address transit inequity challenges faced by persons with disabilities. Addressing this gap involves a multi-pronged approach to gathering information about needs and gaps and assessing existing services that incorporate policy

goals and performance measures. Planning decisions can be categorized into traditional optimization models and multiple attribute approaches. Cui et al. (2019) noted that the first step in determining the impact of accessibility is to obtain the appropriate data to be evaluated at a reasonable level of analysis.

### ***Key Components and Construct***

According to Maxwell (2012), a conceptual framework refers to concepts, beliefs, assumptions, expectations, and related theories that support and inform a research study. It is a strategy for creating coherent, informed, and workable relationships among these design components of the study, including designing research questions, developing goals, and selecting appropriate methods (Maxwell (2012). This study utilized a conceptual framework comprising various attributes. The first component of the conceptual framework is the spatial mismatch theory that posits that people living in areas of poverty, including lower-income households, zero-vehicle households, and other vulnerable populations, lack accessible transportation options to accessing job opportunities because they live far from employment centers (Foth et al., 2013). The intuition from the theory has been used to centralize populations and housing, primarily for African Americans or ethnic minorities in US urban centers or cities. At the same time, employment opportunities were unevenly distributed across metropolitan areas (Gobillon & Selod, 2021). This spatial mismatch has a broader validity beyond this context, including geographic disparities in the availability and accessibility of transportation (Gobillon & Selod, 2021; Fieldhouse, 1999; Holzer, 1991; Steiner et al., 2021). Such disparities, coupled with the lack of accessible transportation, are a challenge faced by transportation-disadvantaged individuals and communities, reducing their access to opportunities (Bardaka et al., 2020). The spatial mismatch theory can help explain the challenge of unmet transit needs.

The second component is microtransit accessibility, which involves three attributes – i.e., availability, coverage, and demographics – used to measure ridership or transit usage (Bouton et al., 2017). The concept of accessibility was initially proposed by Hansen (1959) and defined based on the “potential of opportunities for interaction” (Sharma & Patil, 2021; Bree et al., 2020; Wu et al., 2023). However, it is often unclear how accessibility is measured, especially regarding microtransit usage (Bree et al., 2010; Wu et al., 2023). This is partly because accessibility is not often translated into performance measures that evaluate policies (Handy & Niemeier, 1997). Measuring the ease of access or accessibility to microtransit services is essential in evaluating existing services, identifying service gaps, allocating transportation investments, making decisions, and prioritizing the provision of sufficient and equal accessibility (Wu et al., 2023; Al et al., 2011; Mamun, 2011). Accessibility can be best considered and achieved through a thoughtful planning process for microtransit service that also believes and addresses coverage, affordability, and geographic and demographic thresholds (Estes, 2014; Pierce et al., 2016; Suen & Mitchell, 2000). The decisions to adopt transit to enhance accessibility often depends on these factors and related attributes such as the cost of infrastructure investment, population density, household income, vehicles per household, demographics, public-transit services, etc., that will increase ridership or transit usage (Bouton et al., 2017). Microtransit accessibility can be interpreted in terms of service availability referring to where and when service is provided in the designed service area and coverage – that is, having sufficient capacity to meet trip demand at their desired times of trip requests by customers (e.g., highest frequency and broadest geographic coverage) (Ryus, 2003; Fayyaz et al., 2017).

Microtransit availability impacts the accessibility of services to various demographic groups (Volinski, 2018). *Accessibility* is microtransit availability based on the service span and service coverage (KFH Group, 2013; Quade, 2003; Godavarthy et al., 2015). According to Fayyaz, Liu, and Porter (2017), the percentage of service coverage and transit level of service places more emphasis

on spatial coverage, service, and frequency. Span of Service considers attributes that address ease of travel to and from trip origins/destinations, such as days of service and frequency of service (Henk & Hubbard, 1996). Coverage attributes include trip, spatial, and temporal coverage (Mamun, 2011; Polzin et al., 2002). Geographic coverage and equitable service distribution are crucial for measuring microtransit accessibility (Polzin et al., 2002). Evaluating the spatial coverage of microtransit accessibility throughout a zone or system is carried out by calculating the percentage of service coverage area and incorporating other transit attributes. Economic, population, and demographic factors, such as service area size, population density, zero-vehicle households, income, and job access, can impact service outcomes. Fixed-route services connect underserved areas, especially high-minority and low-income regions. This is because bus riders are mostly transit-dependent individuals composed of minorities, persons with disabilities, older adults, and low-income residents who are more transit-dependent (Garrett & Taylor, 1999; Taylor & Morris, 2015; Murray Davis, 2001).

The third component is the multiple-attribute decision-making problem, where several different and sometimes conflicting attributes accompany competing alternatives. Multi-Attribute Decision-Making (MADM), first introduced by Churchman et al. (1957) as a theory of solving decision problems, presents an alternative approach to solving decision problems most effectively. It also addresses the single-threshold limitation of the cumulative methods by weighting attributes (Fayyaz et al., 2017). Improving the reliability of decision support systems that support consensus is critical for advancing essential policy objectives such as accessibility (Pena et al., 2020).

## **4.4 Research Questions**

This paper will discuss the following specific questions:

1. How do practitioners think about microtransit accessibility?

2. To what extent does an organization use multi-attribute decision-making techniques to support decisions on microtransit adoption to increase transit accessibility, and how do these relationships impact microtransit accessibility?

## **4.5 Research Methods**

This section provides a concise summary of the methodologies used in this study to identify the critical variables required for evaluating microtransit accessibility. The study proposes a MADM (Multi-Attribute Decision Making) approach involving a three-step process to create a composite matrix to calculate microtransit accessibility by comparing accessibility attributes. This approach aims to minimize the need for substantial amounts of data while considering the limitations of available data sources. The choice of methods also makes the end user of the product.

### ***Case Selection***

Washington, D.C., is a case study area for emerging transportation technologies. The region has a population of 5.7 million (MWCOG, 2023), with 1.76 vehicles per household and 69.3% of commuters being solo drivers (Feigon & Murphy, 2016). The Washington Metropolitan Area Transit Authority (WMATA) provides fixed-route and ADA paratransit services. This study analyzes micro transit accessibility in the Washington, D.C. region, i.e., in Montgomery County and Prince George's County in Maryland.

This research focuses on two microtransit services, Ride On Flex (in Montgomery County) and PGC Link (in Prince George's County). The former operates in two zones in Rockville and Wheaton-Glenmont in Montgomery County, while the latter covers a single zone in Oxon/Fort Washington in Prince George's County. The selection of these cases was based on several factors. Firstly, both services operate in a similar geographic region and have comparable funding and operational challenges in providing similar transit services. For example, Prince George's and Montgomery Counties experience similar traffic congestion and limited high-capacity transit infrastructure. Both counties have implemented innovative microtransit systems

that offer app-based, on-demand services instead of fixed-route transit. These systems were launched in the last five years, allowing for policies to be initiated and implemented through local ordinances at the state level. These counties have large metropolitan areas with high demand for transit services, making them ideal for implementing such systems. Additionally, since I am based in Washington, D.C., data availability and ease of data collection were key factors in selecting the cases. These jurisdictions presented an advantage for higher survey response rates, making it easier to identify and contact interviewees and conduct follow-up interviews more quickly.

The research began by thoroughly reviewing successful microtransit literature and relevant data on multi-attribute decision-making frameworks, microtransit planning, and design processes. This was followed by finding appropriate data sources through an electronic search on Google Scholar. To guide the search, a narrative review format was used, as described by Wee and Banister (2016). The data sources included journal articles and grey literature, such as conference proceedings, textbooks, reports, dissertations, and unpublished working papers. This research identified vital resources on the MADM framework, which led to selecting MPI, LOS, and WAS as three metrics that can be assessed in the framework.

This case study utilizes a mixed-method approach based on a three-step Multiple Attribute Decision Making (MADM) method. Data from interviews and an online survey were also used. As discussed in the previous chapter, an online survey of 28 questions was distributed through listservs between November 14, 2022, and March 25, 2023. Expert interviews were conducted with local transit practitioners, officials, and leaders. The target goal was to interview about ten experts with direct involvement and experience in transit and microtransit services, including individuals with knowledge of policy and planning of microtransit service design. The same interview questionnaire guide and survey instructions were used to collect data for both topics. Chapter 3 provides a detailed explanation of the approach, data, and methods employed. Appendix A contains a copy of the survey questions. The draft interview question guide and Virginia Tech consent form can be found in Appendix B. Table 15 provides a sample of interview variables and question prompts.

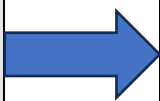
### **Table 15 Interview Data Variables and Question Prompts**

Variable		Question
Service Area Characteristics within Zone	Population	What is the population density?
	Jobs	What is the employment density?
	Land Use	What is the land use pattern?
	Zones	How many zones are in operation?
	Square miles	What is the square mile radius per zone?
Service Area Provision within the microtransit zone	First Mile-Last Mile	What are and how many FM-LM connections are served?
	Bus stops	Are the bus stops designated or virtual?
	Days of Service	How many days does your service operate?
	Service hours	What are the days and hours of operation?
	Wait times	How long is the wait between the vehicle request and the vehicle arrival?

### 4.5.1 The Three-Step MADM Approach

Three variables were used to assess microtransit accessibility for this study, including days of service, hours of service, and ease of access to opportunities (Godavarthy et al., 2015; Quade, 2003; Danaher, 2000; KFH Group, 2013; Polzin et al., 2002). The proposed framework requires specific criteria and corresponding indicators (Hassan et al., 2013). Table 16 shows how the variable matches the method used and data inputs.

**Table 16 Assessment Framework**

Microtransit Accessibility		Variable	Method	Data Source
		Wait-time	On-Time Performance	Interview, Survey, or Agency Data
		Ease of access to opportunities	MPI	Derived from Remix
		Days of Service	LOS	Calculated based on LOS
		Hours of Service	LOS	Calculated based on LOS

In this study, MADM is used to assess microtransit accessible based on a composite framework that include three methods: (1) microtransit propensity index, (2) level of service, and (3) weighted average score (Godavarthy et al., 2015; KFH, 2019; Sevgi et al., 2022).

#### ***Microtransit Propensity Index (MPI)***

Microtransit Propensity Index (MPI), a modified version of the Transit Propensity Index (TPI), assessed several factors like population density, number of job opportunities, household income, race, ethnicity, and availability of personal vehicles. The index indicates the relative demand for transportation services in a particular area. Microtransit zones within 1.5 miles of a transit hub and with easy access to transit and other opportunities score higher. However, physical accessibility and availability of fixed-route bus services can limit microtransit service success. In this study, MPI determined the ease of access to opportunities (Lang, 2018; Erdoğan et al., 2023; Dean & Kockelman, 2021). The MPI formula is below (Table 17).

$$\frac{(((PD + HHD + PBP + PNV) - SWD)(ID + TC))}{(EFR)}$$

**Table 17 Microtransit Propensity Scoring System**

1 - Below average	The metric was below the study area's average
2 - Above average	Metric was greater than the study area average but less than one standard deviation from the mean.
3 - High	The metric was more significant than one standard deviation from the mean.
4 - Very high	The metric was more significant than two standard deviations from the mean.

The Transit Cooperative Research Program (TCRP) published the Transit Capacity and Quality of Service Manual, 2nd Edition, which provides guidelines on the population and job densities necessary to support transit services. According to the manual, areas with a density of at least three households per acre (six people per acre) can support hourly fixed-route transit service. On the other hand, microtransit services are a more suitable option for areas with lower densities, where fixed-route services may not be feasible.

**Level of Service (LOS)**

The Level of Service (LOS) method is a way to assess demand-responsive transit using Transit Capacity. In this study, LOS includes three measures of microtransit accessibility relating to coverage that provides for days of service, hours of service, and ease of access to opportunities (Godavarthy et al., 2015; Quade, 2003; Danaher, 2000; KFH Group, 2013; Polzin et al., 2002). Microtransit availability is critical to determining service coverage and can be correlated to different demographic groups. It is measured by service span in terms of the number of days per week and hours per day, making it an essential metric for assessing service availability (Godavarthy et al., 2015; KFH Group, 2013; Henk & Hubbard, 1996; Danaher, 2000; Molinski, 2018). LOS applies to two variables – i.e., service hours and days of service. The comparison results are organized in a matrix, and values are assigned for easy comparison (Table 18).

**Table 18 LOS Measures Based on Demand Response Service**

<b>Rating</b>	<b>Hours per day</b>	<b>Days per week</b>						
		6–7	5	3–4	2	1	0.5*	<0.5
<b>High</b>	<b>≥16.0</b>	LOS 1	LOS 2	LOS 4	LOS 5	LOS 6	LOS 7	LOS 8
<b>Mid-High</b>	<b>12.0–15.9</b>	LOS 2	LOS 3	LOS 4	LOS 5	LOS 6	LOS 7	LOS 8
<b>Mid</b>	<b>9.0–11.9</b>	LOS 3	LOS 4	LOS 4	LOS 6	LOS 6	LOS 7	LOS 8
<b>Mid-Low</b>	<b>5.0–8.9</b>	LOS 5	LOS 5	LOS 5	LOS 6	LOS 7	LOS 7	LOS 8
<b>Low</b>	<b>&lt;5**</b>	LOS 6	LOS 6	LOS 6	LOS 7	LOS 7	LOS 8	LOS 8

Source: Godavarthy et al. (2015)<sup>29</sup>

### **Weighted Average Scores (WAS) Method**

This research employs the Weighted Average Scores (WAS) method to evaluate the significance of assessment criteria and performance indicators for microtransit accessibility. The WAS method is used to identify areas that lack proper transit service, also known as transit deserts, by examining accessibility measures for those regions. The WAS method is an Analytical

<sup>29</sup> “The second edition of the TCQSM uses “< 4 hours” as the lowest level for hours of service, but this was revised to “< 5 hours” in the third edition, which being used in this study. The third edition of the TCQSM no longer combines days and hours of service into a single level of service measure.” Source: TCQSM, 2nd Edition; TCQSM, 3rd Edition.

Hierarchical Process (AHP) technique that ranks decision alternatives (Godavarthy et al., 2015; KFH, 2019; Sevgi et al., 2022). Finally, the data was extrapolated, visualized, and verified using Remix.<sup>30</sup> To enable easy comparison, a value is assigned to each WAS comparison. Table 19 presents the proposed “WAS Comparison Matrix” for this study.

**Table 19 WAS the Matrix**

<b>Relative Importance of Accessibility</b>	Equal Importance	Moderate Importance	Strong Importance	Very High Importance	Extreme Importance
<b>Comparison</b>	Below average (less critical)	Above average (moderately important)	High (strongly important)	Very High (strongly more critical)	Extremely High
<b>(WAS) Assigned Value</b>	1	2	3	4	5
<b>Rating</b>	Low	Low-Mid	Mid	Mid-High	High

*Source: Adapted and modified from Aguilar-Lasserre et al., 2009*

“Importance” refers to the value assigned to a criterion by a transit expert based on survey data. To minimize bias toward specific criteria, weights and ranks are given to each variable or measure (Aguilar-Lasserre et al., 2009). For this study, Table 20 outlines the elements and corresponding values used for scoring and weighting related variables.

**Table 20 WAS Weighing Microtransit Propensity Scoring System**

<b>Value, Rating Weight</b>	<b>Description of metric</b>
<b>1 – Low</b>	Below is the study area's average
<b>2 – Mid-Low</b>	Average
<b>3 – Mid</b>	Greater than the study area average but less than one standard deviation from the mean
<b>4 – Mid-High</b>	Greater than one standard deviation from the mean
<b>5 – High</b>	Greater than two standard deviations from the mean

*Source: Adapted and modified from Sevgi et al. (2023).*


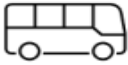




## 4.5.2 The MADM Case Study

### Ride On Flex

<sup>30</sup> Remix is a proprietary platform used for transportation planning software.

Ride-On Flex is an on-demand shuttle service launched in June 2019. It provides corner-to-corner type last-mile transit in two flex zones in Montgomery County. The Rockville zone is 0.7 sq miles served by one vehicle, while the Wheaton-Glenmont zone is 3.4 sq miles served by two vehicles. There are no fixed stops or schedules. Flex service is available from Monday to Friday, with different hours in Rockville and Wheaton-Glenmont. Table 21 shows Rockville’s hours are 9:00 a.m. to 3:30 p.m. Wheaton-Glenmont’s hours are 6:00 a.m. to 9:00 a.m. and 3:30 p.m. to 7:00 p.m.<sup>31</sup> The service can be scheduled through Via technology. County drivers and vehicles operate the service. Montgomery County also offers paratransit services such as Call-n-Ride, Same Day Access, and Medicaid Transportation.

**Table 21 Characteristics of Montgomery County, Ride On Flex Study Area and Ridership**

Flex Zone	 Service Spans	 Service Vehicles	 Zone Size (Sq. Mi.)	 Service Intent	 Most Popular Destination	 Multi-Stage Trips (3 or more linked daily trips)
Rockville	9:00 am to 3:30 pm	1	0.7	Errands/ Public Services	Rockville Metro Station	9%
Wheaton/ Glenmont	6:00 am to 9:00 am 3:30 pm to 7:00 pm	2	3.4	First-Mile/ Last-Mile to Transit	Glenmont Metro Station	3%

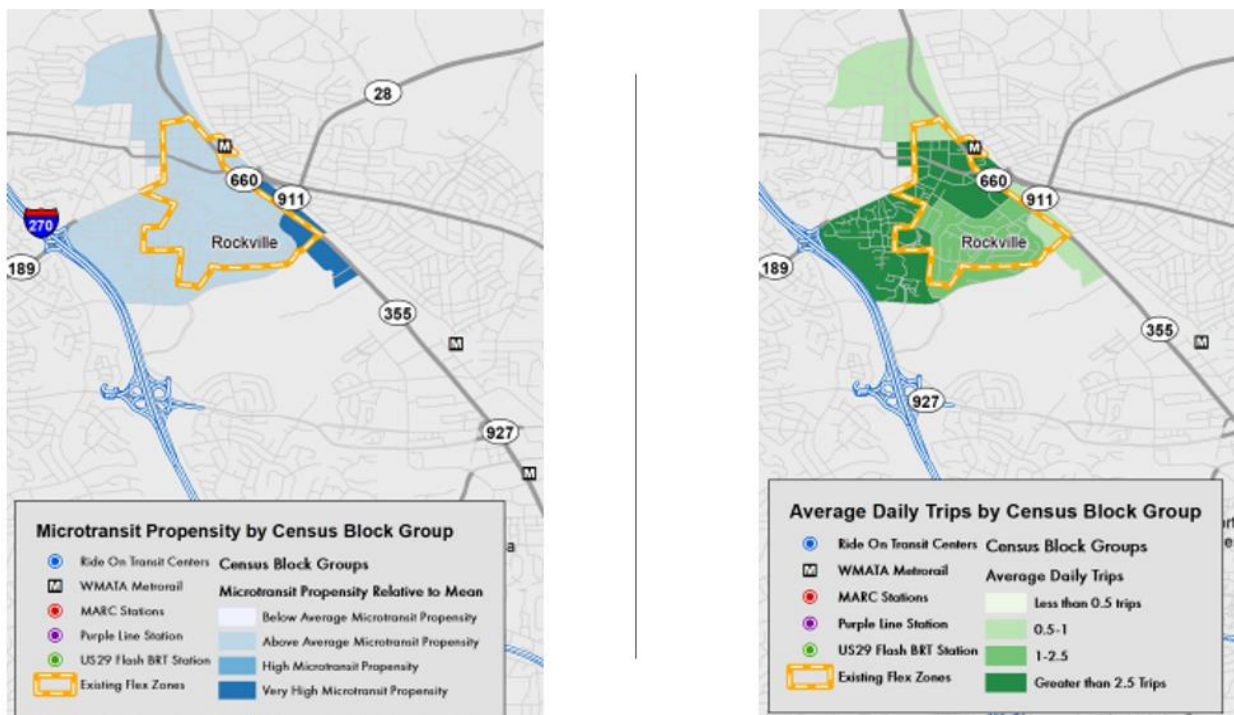
*Source: Montgomery County Department of Transportation (MCDOT)*

## Rockville zone

The Rockville zone covers an area of approximately 0.7 square miles. It begins at Hungerford Drive and Beall Avenue intersection and extends westward to Beall and North Washington Street. The zone’s boundaries include Rockville Pike to the east, Wootton Pkwy and

<sup>31</sup> KFH (2020, August 1). *Ride On Flex Microtransit Performance Assessment*. Mwcog.org/. Retrieved September 9, 2022, from [https://www.mwcog.org/assets/1/6/FY20\\_Montgomery\\_-\\_Flex\\_Microtransit.pdf](https://www.mwcog.org/assets/1/6/FY20_Montgomery_-_Flex_Microtransit.pdf)

Wootton Oaks to the south, and New Mark Commons and The Villages at Towers Oaks to the southwest. The zone covers the area south of Washington Street along Maryland to Avenue West Argyle Street and includes Monroe Street along with Rockville Pike and the Rockville Metro. It also encompasses several residential buildings (Figure 22).<sup>32</sup>



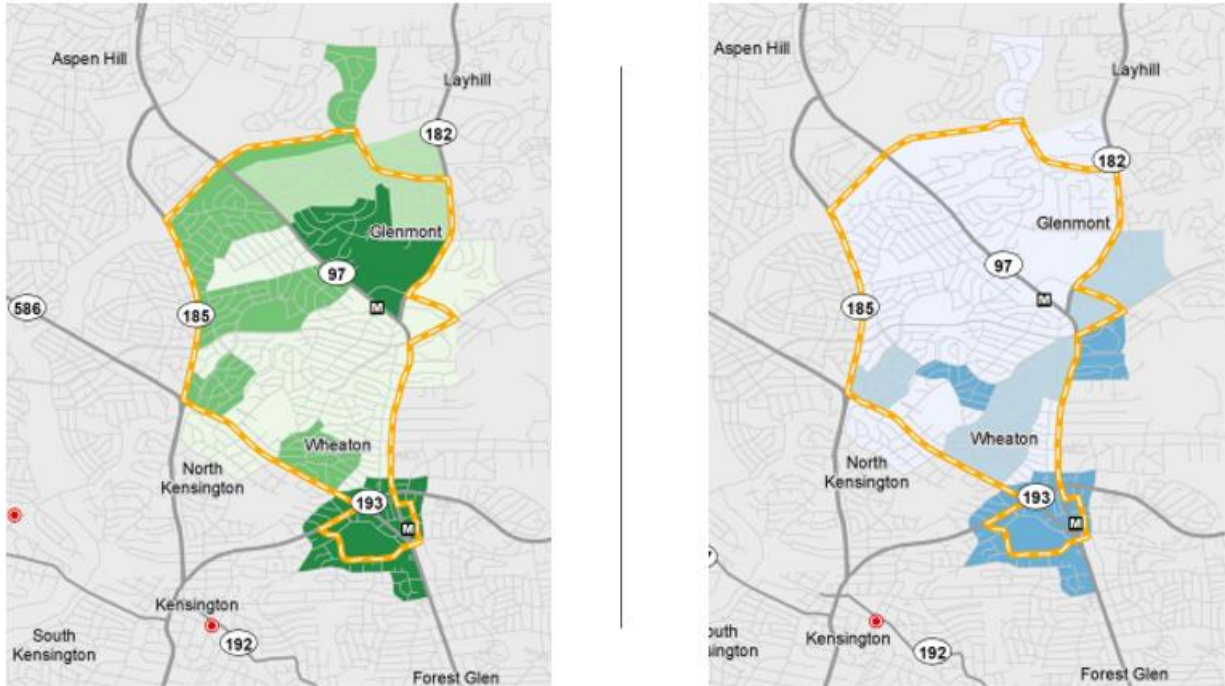
Source: 2020 MCDOT Ride On Flex Microtransit Performance Assessment  
**Figure 22 Ride On Flex Rockville Zone**

## Glenmont/Wheaton

Wheaton-Glenmont Zeon is 3.4 square miles and is served by two vehicles. The zone extends from the intersection of Hewitt Avenue and Rippling Brook Drive in the north to University Boulevard West and Valley View Avenue in the south. Georgia Avenue and Hewitt Avenue bound it in the west, Matthew Henson Trail, Connecticut Avenue, and Veirs Mill Road in the southwest, and

<sup>32</sup> KFH (n.d.). *Traveling in a Flex zone? Lucky you!* [www.Montgomerycountymd.gov/DOT](http://www.Montgomerycountymd.gov/DOT). Retrieved December 9, 2023, from <https://www.montgomerycountymd.gov/DOT-Transit/flex/>

Prichard Road, Cobble Hill Terrace, Wheaton Metro, and Price Avenue to Georgia Avenue in the north (Figure 23).



Source: 2020 MCDOT Ride On Flex Microtransit Performance Assessment  
Figure 23 - Ride On Flex Glenmont Zone

## Overview of the Rockville & Wheaton-Glenmont Flex Zones

The Wheaton-Glenmont and Rockville zones were designed to provide on-demand transit services for commuters using the Metro stations. In the Wheaton-Glenmont area, 69% of morning trips end at one of the two Metro stations in the zone. On the other hand, in the Rockville area, 21% of trips finish at the Rockville Metrorail station, while only 7% originate from the same station.<sup>33</sup> These zones' primary objective is to cover residential neighborhoods and commercial hubs while serving as the first and last-mile connections. The Wheaton-Glenmont zone is intended to help residents fill the gap in their daily commutes. In contrast, the Rockville zone connects local activity

<sup>33</sup> KFH (2020, August 1). *Ride On Flex Microtransit Performance Assessment*. Mwcog.org/. Retrieved September 9, 2022, from [https://www.mwcog.org/assets/1/6/FY20\\_Montgomery\\_-\\_Flex\\_Microtransit.pdf](https://www.mwcog.org/assets/1/6/FY20_Montgomery_-_Flex_Microtransit.pdf)

centers for daytime errands and trips. These differences are also reflected in the service spans and the higher percentage of multi-stage trips the Rockville zone serves.

## PGC Link

The PGC Link was launched in November 2020 to provide on-demand neighborhood transit service in the Oxon Hill and Fort Washington zones. Rides are booked through the TransLoc app or by calling the call center, which a contractor operates. The county provides the vehicles and drivers who operate the service (Table 22).

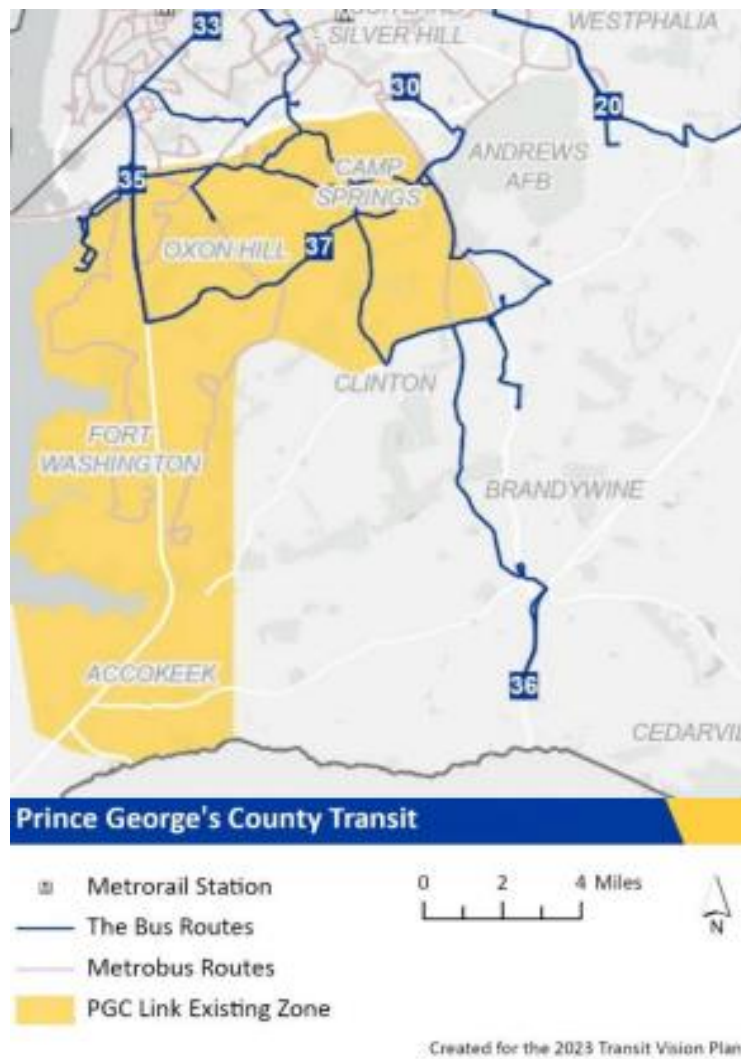
**Table 22 Overview of PGC Link**

Microtransit	Zone	Started	Service Spans	Service Area (Sq. Mi)	Average Daily Ridership
PGC Link	Fort Washington Zone	2020	10 a.m. – 3:30 p.m.	22	15

*Source: Prince George’s County Department of Public Works and Transportation*

### Fort Washington Zone

According to Department staff, with the Prince George’s County Department of Public Works and Transportation, the PGC Link service covers about 22 square miles. It connects various communities in Accokeek and the Southern end of the county. The zone service operates two vehicles curb-to-curb on weekdays from Monday to Friday from 10 a.m. to 3:30 p.m. with an average daily ridership of 15 trips. I-495 borders the zone on the north, the Potomac River on the west, Old Fort Road on the south, Bock Road, and the communities of Palmers Corner, Friendly, Fort Washington Forest on the west, Accokeek, and Berry Road-MD 228 on the south (Figure 24).



Source: Department of Public Works and Transportation  
**Figure 24 PGC Link Fort Washington Zone**

## 4.6 Case Study Findings and Results

During the interview period, 11 individuals were interviewed – five men and six women. Thirty-six percent (n=4) of respondents were transportation planners, 27% (n=3) of those interviewed held executive or senior manager positions, 18% for transit managers, and 18% for other city/county officials. The interview representation by jurisdiction is as follows: three from Prince George’s County (PGC Link), two from Washington DC (DC Neighborhood Connect), two from Montgomery County (Ride On Flex), two from Arlington County, one from Prince William County, and one from the City of Alexandria. After each interview, a follow-up questionnaire was sent to the

interviewees to gather more detailed and specific data. The responses and answers to the questions were documented in a pseudo-anonymous manner. Tables 23 and 24 summarize the interview responses, including data from other sources.

**Table 23. Spatial Coverage Variables and Attributes**

Variables	Attributes	Ride On Flex		PGC Link
		Wheaton-Glenmont	Rockville	Fort Washington
Ease to access ("coverage")	Population	30,100	5,300	85,800
	Employment	3,000	8,000	12,200
	Square Miles	3.4	0.7	30
	Low Income	60%	77%	65%
	Poverty Level	13%	10%	6.3%

*Data source: U.S Census 2016-2020 through the Remix Planning Platform.*

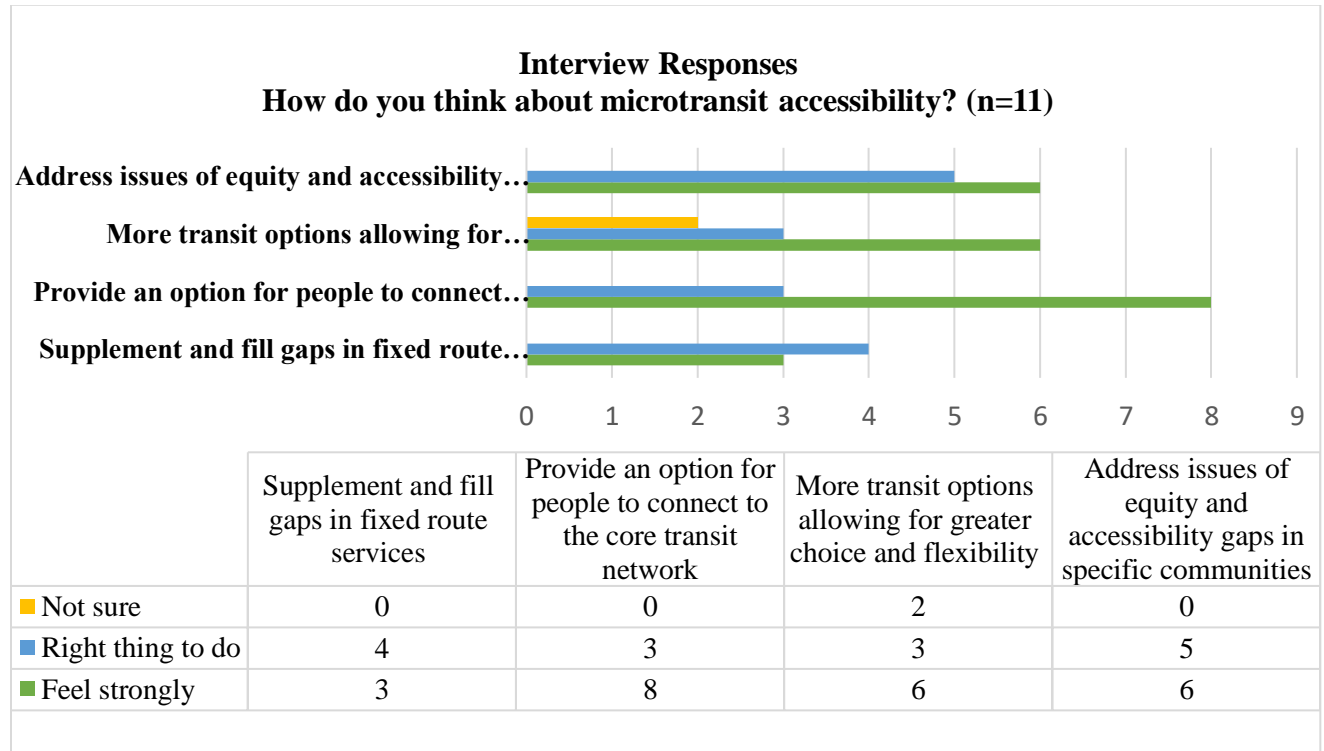
**Table 24. Level of Service Variables and Attributes**

		Ride On Flex		PGC Link
		Wheaton-Glenmont	Rockville	Fort Washington
<b>Service Span</b>	Start /end times	6:00 a.m./9:00 a.m. & 3:30 p.m./7:00 p.m.	9:00 a.m./3:30 p.m.	10 a.m./3:30 p.m.
<b>Hours of service</b>	Days per week	5	5	5
	Hours per week	8.5	6.5	5.5
	Weekend	0	0	0
	Wait times	0	0	0

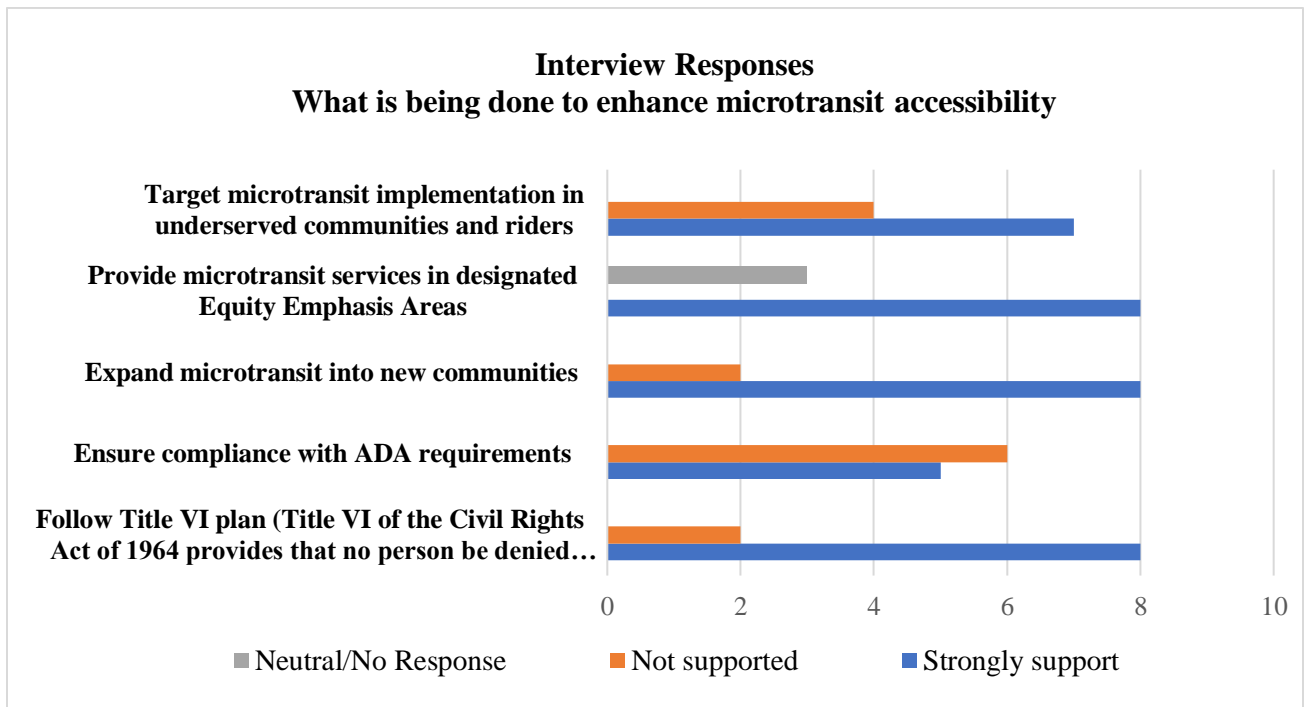
***How do practitioners think about microtransit accessibility?***

Figures 25 and 26 summarize interview responses for two questions focusing on (1) *how do you think about microtransit accessibility?* Furthermore, (2) *what is being done to enhance microtransit accessibility.* Most practitioners view microtransit accessibility regarding service availability, while local officials discuss it from a transit equity perspective. Follow-up questions revealed plans to expand microtransit and improve accessibility in underserved communities. For instance, one of the officials managing the selected case study areas noted that “the county plans to expand microtransit by adding new zones to improve accessibility to transit across different communities.” Another department staff mentioned existing and past studies to expand

microtransit to more zones across the county to deliver microtransit to communities with limited access to fixed route transit options. The eventual goal was to make microtransit widely available weekdays and weekends, and users-friendly to attract more youths, seniors, and individuals with disabilities to use microtransit.

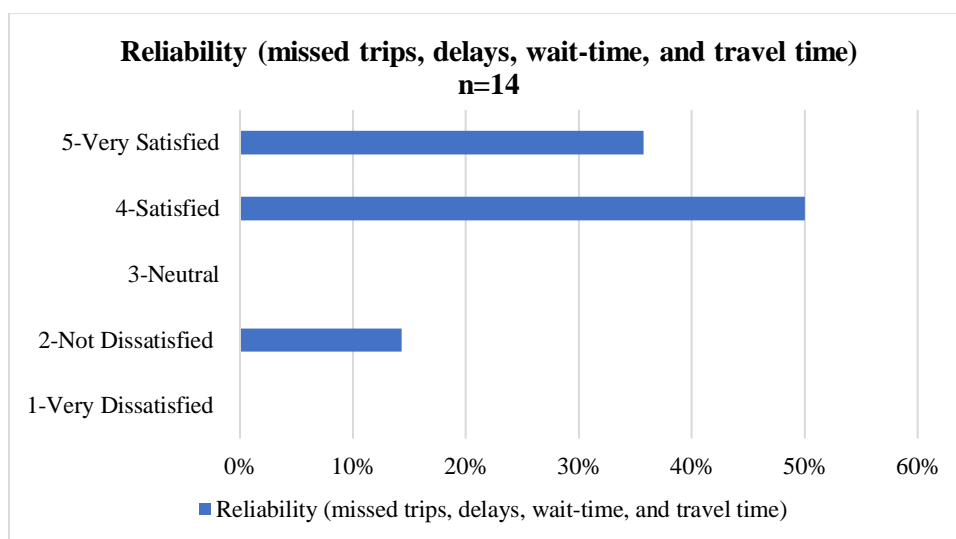


*Figure 25: What do you think about microtransit accessibility?*

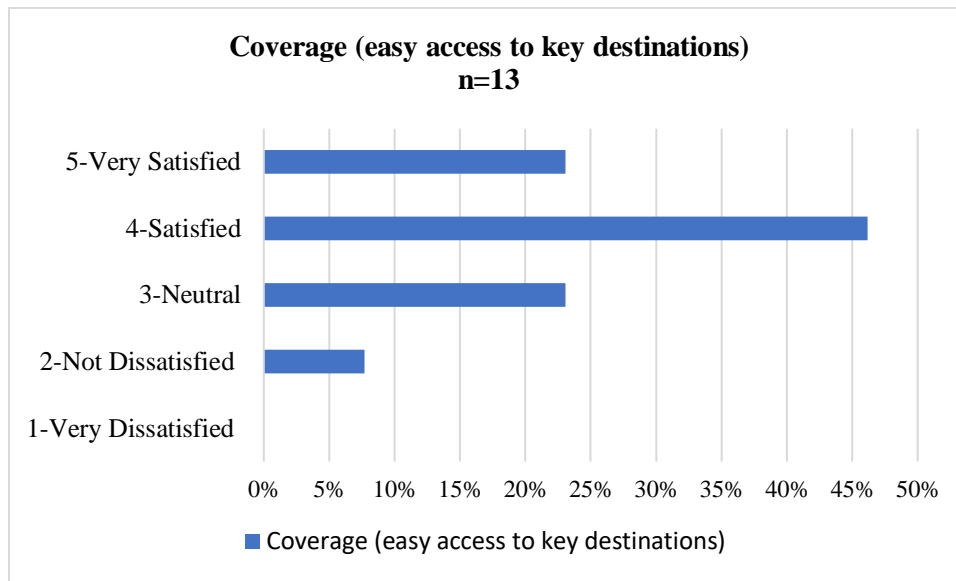


**Figure 26** *What is being done to enhance microtransit accessibility (follow-up question) Satisfaction with the service reliability and coverage*

Figures 27 and 28 indicate that survey respondents expressed high satisfaction with on-demand microtransit service reliability at 86%, which includes missed trips, delays, wait time, and travel time. Additionally, 69% of respondents were satisfied with the coverage of on-demand services, which provided easy access to critical destinations.



**Figure 27** *Reliability (missed trips, delays, wait time, and travel time)*



**Figure 28 Coverage (easy access to critical destinations)**

*To what extent does an organization use multi-attribute decision-making techniques to support decisions on microtransit adoption to increase transit accessibility, and how do these relationships impact microtransit accessibility?*

During interviews, respondents mentioned using various tools to plan, evaluate, and assess microtransit services. One senior official stated that the department used spreadsheets, GIS tools, Via modeling tools, Remix, and demand models for planning and evaluating county micro-transit services. Municipalities also use different performance measures to monitor microtransit services, such as zero-vehicle households, census data on population and income levels, and more. A planning manager revealed that changes to the existing microtransit service require an equity analysis involving different information and methods. Both PGC Link and Ride On considered microtransit accessibility and its impacts integral to the service design and performance assessment process.

Table 25 below presents evidence of MADM factors across three micro transit zones.

**Table 25 Microtransit Accessibility Composite Matrix**

Variable	Method	Wheaton-Glenmont	Rockville	Fort Washington
Ease of access	MPI	Mid-Low	Mid-High	Low
Hours of service	LOS	8.5	6.5	5.5

Days of Service	LOS	5	5	5
-----------------	-----	---	---	---

MPI was computed using Remix planning software.

This study has identified essential applications of the MADM framework in planning decision-making for microtransit implementation. It provides an in-depth analysis of how microtransit accessibility can be measured and understood. The findings suggest that unlike traditional paratransit and fixed-route buses, new technologies like microtransit cater to a previously unfulfilled demand for convenient and direct transportation. Although forms of transit like taxis and paratransit also offer on-demand services, the study found variations in opinions and objectives on transit practitioners' view of microtransit accessibility. The framework led to selecting three metrics: MPI, LOS, and WAS. These metrics were used to evaluate microtransit accessibility based on a composite framework. The ranking was based on the importance of accessibility in the policy and planning of microtransit service.

- LOS measured microtransit accessibility based on the service span in terms of the number of days per week and hours per day. LOS is a crucial metric for assessing service availability. The coverage data for PGC Link and Ride On Flex were compared using a matrix with assigned values for each system. LOS matrix or tables made it easy to compare different systems based on varying demand levels and service areas (Table 20). The results of LOS show that micro transit accessibility was found to be moderately accessible for all three zones reviewed (i.e., the hours per day ratings fell between 5.0 - 8.9, resulting in a LOS-5 rating). Therefore, as officials in Prince George's and Montgomery Counties continue to plan and deploy microtransit services, microtransit service design must continue to prioritize accessibility needs.
- Geographic coverage and ease of access to the core public transportation network are key microtransit accessibility factors. MPI measures the relative coverage and ease of access in a particular area. It is determined by several factors such as proximity to a transit network,

population density, employment density, household density, percentage of households without vehicles, and percentage of families living below the poverty line. These factors were calculated based on how much they deviate from the average of the study area. The assessment shows that PGC Link does not connect to a primary bus or rail station compared to the Ride-On Flex zones in Rockville and Wheaton-Glenmont. While the PGC Link service is available to lower-income and zero-car households, usually disadvantaged communities, its lack of connectivity to the core transit network limited its accessibility. In designing future microtransit services, the county planner and policymakers should clearly define performance measures, including expected outcomes based on established agency mandates informed by stakeholder preferences.

As these services evolve, they will develop microtransit accessibility measures to inform adoption efforts. Equity and environmental justice principles must guide microtransit accessibility measures and targeted outcomes. To better optimize short and long-term microtransit accessibility, performance outcomes must be measured relative to expectations for the performance of microtransit and other transit modes over a defined period. A proactive approach to developing accessibility indicators is necessary. The WAS technique can be used to assess and rank decision alternatives and evaluate microtransit coverage based on the level of service in a specific area. Context-based planning and design for microtransit will benefit from using an analytical approach to exploring and sequencing actions using MADM, which can help identify service design options that provide better accessibility and operational capabilities over a wide range of alternatives. In addition, the use of MADM will support future decision-making under deep uncertainty and help identify design options that positively influence the performance of the microtransit system. The WAS approach can be employed to identify key variables and data needs and determine the required weight of the attributes to calculate microtransit accessibility.

## 4.7 Conclusion

MADM offers a framework that could be used to support microtransit planning and service design. This study provides municipalities and transit agencies with a three-step methodology for building scenarios and making informed decisions about microtransit accessibility compared to the many proprietary simulation tools for microtransit planning and service design. This study adds to the current body of literature on microtransit accessibility by identifying, categorizing, and integrating essential concepts related to this topic. Additionally, it addresses gaps in the literature by presenting components and steps that can aid in evaluating microtransit accessibility. Like many new transit technologies, exploring micro transit accessibility can be challenging to keep up with because of the many levels and layers of decision-making involved. This framework will help make informed decisions regarding microtransit planning and service design.

This research indicates that the microtransit propensity is mid-high for Rockville, mid-low for Wheaton-Glenmont zones in Montgomery County, and low for Oxon Hill in Prince George's County. The findings also reveal that attributes such as low-income populations with lower job accessibility, longer access time to jobs, and zero-vehicle households were factored in the planning and design simulation of the service area. This supports previous studies that have shown microtransit as an option to fill gaps in fixed-route transit and address equity and accessibility challenges. Both systems plan to expand and provide more accessibility services for Ride On Flex and PGC Link. However, compared to fixed route and paratransit services, microtransit accessibility is limited in terms of coverage and level of service.

The study proposes a multi-attribute decision-making approach for evaluating microtransit accessibility. The proposed three-step MADM approach includes the microtransit propensity index, level of service measures, and weighted average scoring to analyze and rank related attributes. The

study finds that in both cases, Ride On Flex and PGC Link staff used various data and different performance measures to monitor microtransit services, such as zero-vehicle households and census data on population and income levels, to adopt microtransit or support enhancements. Nevertheless, similar microtransit projects, like PGC Link and Ride-On Flex, exhibit different outcomes when evaluated using a multi-attribute decision-making (MADM) approach.

As microtransit evolves and is integrated into the transit landscape, more research is necessary to determine how transit agencies define accessibility and how that impacts policy and planning decision-making for microtransit deployment. This study adds to the literature on microtransit accessibility. It contributes to research on MADM in planning and policy considerations. However, one limitation of this research is that the three components used in this study to calculate microtransit accessibility have different assumptions, which limit the use of standardized values to compare accessibility attributes. Future research on a standardized measure for microtransit accessibility is needed.

## 4.8 References

- Acheampong, R. A., Siiba, A., Okyere, D. K., & Tuffour, J. P. (2020). Mobility-on-demand: An empirical study of internet-based ride-hailing adoption factors, travel characteristics, and mode substitution effects. *Transportation Research Part C: Emerging Technologies*, 115, 102638.
- Akincilar, A., & Dagdeviren, M. (2014). A hybrid multi-criteria decision-making model to evaluate hotel websites. *International Journal of Hospitality Management*, 36, 263-271.
- Airgood-Obrycki, W., Hanlon, B., & Rieger, S. (2021). Delineate the US suburb: An examination of how different definitions of the suburbs matter. *Journal of Urban Affairs*, 43(9), 1263-1284.
- Al Mamun, M. S., & Lownes, N. E. (2011). A composite index of public transit accessibility. *Journal of Public Transportation*, 14(2), 69-87.
- Aguilar-Lasserre, A. A., Bautista, M. A. B., Ponsich, A., & Huerta, M. A. G. (2009). An AHP-based decision-making tool for the solution of multiproduct batch plant design problem under imprecise demand. *Computers & Operations Research*, 36(3), 711-736.
- Alonso-González, M. J., Liu, T., Cats, O., Van Oort, N., & Hoogendoorn, S. (2018). The potential of demand-responsive transport as a complement to public transport: An assessment framework and an empirical evaluation. *Transportation Research Record*. <https://doi.org/10.1177/0361198118790842>
- Aruldoss, M., Lakshmi, T. M., & Venkatesan, V. P. (2013). A survey on multi criteria decision making methods and its applications. *American Journal of Information Systems*, 1(1), 31-43.

- Alterman, R. (1988). Adaptive planning. *Cognitive science*, 12(3), 393-421
- Aman, J. J. C., & Smith-Colin, J. (2020). Transit Deserts: Equity analysis of public transit accessibility. *Journal of Transport Geography*, 89, 102869
- APTA. 2021. *Microtransit* [Online]. Available: <https://www.apta.com/research-technicalresources/mobility-innovation-hub/microtransit/> [Accessed]
- Beimborn, E. A., Greenwald, M. J., & Jin, X. (2003). Accessibility, connectivity, and captivity: impacts on transit choice. *Transportation Research Record*, 1835(1), 1-9.
- Bouraima, M. B., Tengecha, N. A., Stević, Ž., Simić, V., & Qiu, Y. (2023). An integrated fuzzy MCDM model for prioritizing strategies for successful implementation and operation of the bus rapid transit system. *Annals of Operations Research*, 1-32.
- Bouton, S., Hannon, E., Knupfer, S., & Ramkumar, S. (2017). *The future (s) of mobility: How cities can benefit*. McKinsey Global Institute.
- Bree, S., Fuller, D., & Diab, E. (2020). Access to transit? Validating local transit accessibility measures using transit ridership. *Transportation Research Part A: Policy and Practice*, 141, 430-442.
- Botzow, H. (1974). Level-of-service concept for evaluating public transport. *Transportation Research Record*, 519, 73-84.
- Buenk, R., Grobelaar, S. S., & Meyer, I. (2019). A framework for the sustainability assessment of (Micro) transit systems. *Sustainability*, 11(21), 5929.
- Churchman, C. W., Ackoff, R. L., & Arnoff, E. L. (1957). Introduction to operations research.
- Clark, H. M. (2017). Who rides public transportation.
- Clifton, K. J., & Handy, S. L. (2001). Evaluating neighborhood accessibility: Possibilities and practicalities. *Journal of Transportation and Statistics*, 4(2-3), 67.
- Cui, B., Boisjoly, G., El-Geneidy, A., & Levinson, D. (2019). Accessibility and the journey to work through the lens of equity. *Journal of Transport Geography*, 74, 269-277.
- Danaher, A. R. (2000). *New Transit Capacity and Quality of Service Manual* (No. E-C018).
- Deng, J., Zhan, J., & Wu, W. Z. (2021). A three-way decision methodology to multi-attribute decision-making in multi-scale decision information systems. *Information Sciences*, 568, 175-198.
- Dean, M. D., & Kockelman, K. M. (2021). Spatial variation in shared ride-hail trip demand and factors contributing to sharing: Lessons from Chicago. *Journal of Transport Geography*, 91, 102944.
- Dey, P. K. (2001). Decision support system for risk management: a case study. *Management Decision*.
- Drobne, S., & Lisec, A. (2009). Multi-attribute decision analysis in GIS: weighted linear combination and ordered weighted averaging. *Informatica*, 33(4).
- Erdoğan, S., Nohekhan, A., Shokputov, A., & Sadabadi, K. F. (2023). Multi-Criteria Decision-Making Framework for Determining Public Microtransit Service Zones. *Transportation Research Record*, 03611981231198464.
- Erdoğan, S., Nohekhan, A., Shokputov, A., & Sadabadi, K. F. (2023). Multi-Criteria Decision-Making Framework for Determining Public Microtransit Service Zones. *Transportation Research Record*, 03611981231198464.
- Ermagun, A., & Tilahun, N. (2020). Equity of transit accessibility across Chicago. *Transportation Research Part D: Transport and Environment*, 86, 102461.
- Fayyaz, S. K., Liu, X. C., & Porter, R. J. (2017). Dynamic transit accessibility and transit gap causality analysis. *Journal of Transport Geography*, 59, 27-39.
- Fayyaz, S. K., Liu, X. C., & Porter, R. J. (2017). Dynamic transit accessibility and transit gap causality analysis. *Journal of Transport Geography*, 59, 27-39.
- Fieldhouse, E. A. (1999). Ethnic minority unemployment and spatial mismatch: the case of London. *Urban Studies*, 36(9), 1569-1596.

- Fischer, M. M., & Getis, A. (Eds.). (2010). *Handbook of applied spatial analysis: software tools, methods, and applications* (pp. 125-134). Berlin: Springer.
- Fischer, L. A., Ray, R. S., & King, D. A. (2020). Who decides? Toward a typology of transit governance. *Urban Science*, 5(1), 6.
- Foth, N., Manaugh, K., & El-Geneidy, A. M. (2013). Towards equitable transit: examining transit accessibility and social need in Toronto, Canada, 1996–2006. *Journal of Transport Geography*, 29, 1-10.
- Gan, A., Gui, F., & Tang, L. (2011). System for transit performance analysis using the national transit database. *Journal of Public Transportation*, 14(3), 87-107
- Garrett, M., & Taylor, B. (1999). Reconsidering social equity in public transit. *Berkeley Planning Journal*, 13(1).
- Georgia Planning Association. (2019). Micro-Transit Feasibility Study Hall County, Georgia. *Georgia, GA*.
- Gerçek, H., Karpak, B., & Kılınçaslan, T. (2004). A multiple criteria approach for the evaluation of the rail transit networks in Istanbul. *Transportation*, 31, 203-228.
- Gobillon, L., & Selod, H. (2021). Spatial mismatch, poverty, and vulnerable populations. *Handbook of Regional Science*, 573-588.
- Godavarthy, R. P., Mattson, J., Peterson, D., & Hough, J. (2015). Developing a Method for Assessing National Demand-Response Transit Level of Service. *Journal of Public Transportation*, 18(4), 1-15.
- Handley, J. C., Fu, L., & Tupper, L. L. (2019). A case study in spatial-temporal accessibility for a transit system. *Journal of Transport Geography*, 75, 25-36.
- Handy, S. L., & Niemeier, D. A. (1997). Measuring accessibility: an exploration of issues and alternatives. *Environment and Planning A*, 29(7), 1175-1194.
- Hassan, M. N., Hawas, Y. E., & Ahmed, K. (2013). A multi-dimensional framework for evaluating the transit service performance. *Transportation Research Part A: Policy and Practice*, 50, 47-61
- Hawas, Y. E., Hassan, M. N., & Abulibdeh, A. (2016). A multi-criteria approach of assessing public transport accessibility at a strategic level. *Journal of Transport Geography*, 57, 19-34
- He, J., & Ma, T. Y. (2022). Examining the factors influencing microtransit users' next ride decisions using Bayesian networks. *European Transport Research Review*, 14(1), 47.
- Henk, R. H., & Hubbard, S. M. (1996). Developing an index of transit service availability. *Transportation Research Record*, 1521(1), 12-19.
- Holzer, H. J. (1991). The spatial mismatch hypothesis: What has the evidence shown? *Urban Studies*, 28(1), 105-122.
- Iacono, M, K Krizek, and A El-Geneidy. "Measuring Non-Motorized Accessibility: Issues, Alternatives, and Execution." *Journal of Transport Geography*. 18. (2010): 133-140.
- Jenkins, T. D. (2020). Transit Feasibility Study for Chesterfield County, VA.
- Jung, P. H., Kim, H., Lee, K., & Song, Y. (2022). Examining Day-to-Day Dynamic Transit Accessibility Using Functional Data Analysis. *The Professional Geographer*, 74(3), 503-515.
- Kazemi, M., & Zafar Allahyari, M. (2010). Defining a knowledge management conceptual model by using MADM. *Journal of Knowledge Management*, 14(6), 872-890.
- Kerrigan, M., & Bull, D. (1992). Measuring accessibility-a public transport accessibility index. In *ENVIRONMENTAL ISSUES. PROCEEDINGS OF SEMINAR B HELD AT THE PTRC EUROPEAN TRANSPORT, HIGHWAYS AND PLANNING 20TH SUMMER ANNUAL MEETING, (SEPTEMBER 14-18, 1992), UMIST. VOLUME P354*.
- KFH Group. (2013). Transit capacity and quality of service manual.
- KFH Group. (2019). Demand Response Transit/Microtransit: A Guide for Implementing Flexible Transportation Services. *Arlington County, VA*.

[https://www.arlingtontransit.com/sites/art/assets/File/Arlington\\_County\\_Guide\\_for\\_Flexible\\_Transit\\_red\\_uced2019.pdf](https://www.arlingtontransit.com/sites/art/assets/File/Arlington_County_Guide_for_Flexible_Transit_red_uced2019.pdf). Accessed July 2022

- Kumar, C., Mangaraj, B. K., & Vijayaraghavan, T. A. S. (2015). Mode choice for urban work-based daily trips: a multi-criteria decision-making model using the Analytical Hierarchical Process. *WIT Transactions on The Built Environment*, 146, 627-638.
- LaMondia, J. J., Blackmar, C. E., & Bhat, C. R. (2010, August). Comparing transit accessibility measures: a case study of access to healthcare facilities. In *Transport Research Board 2011 Annual Meeting*. Washington, DC.
- Lang, K. (2018). An Evaluation of a Demand-Responsive Transit Pilot in North Carolina's Research Triangle Park
- Lee, C. H., Cook, S., Lee, J. S., & Han, B. (2016). Comparison of two meta-analysis methods: inverse-variance-weighted average and weighted sum of Z-scores. *Genomics & Informatics*, 14(4), 173.
- Lei, T. L., Chen, Y., & Goulias, K. G. (2012). Opportunity-based dynamic transit accessibility in Southern California: Measurement, findings, and comparison with automobile accessibility. *Transportation Research Record*, 2276(1), 26-37
- Liu, M. (2015). *Urban Transport Project Prioritization Strategy in Developing Countries: A Scenario-Based Multi-Criteria Decision Analysis Perspective* (Doctoral Dissertation, Columbia University).
- Lindblom, C. E. (1959). The science of "muddling through". *Public Administration Review*, 79-88.
- Lucken, E., Frick, K. T., & Shaheen, S. A. (2019). "Three Ps in a MOD:" Role for mobility on demand (MOD) public-private partnerships in public transit provision. *Research in Transportation Business & Management*, 32, 100433.
- Malekzadeh, A., & Chung, E. (2020). A review of transit accessibility models: Challenges in developing transit accessibility models. *International Journal of Sustainable Transportation*, 14(10), 733-748.
- Martens, K., Golub, A., & Robinson, G. (2012). A justice-theoretic approach to the distribution of transportation benefits: Implications for transportation planning practice in the United States. *Transportation Research Part A: Policy and Practice*, 46(4), 684-695.
- Martinez, L. M., & Viegas, J. M. (2017). Assessing the impacts of deploying a shared self-driving urban mobility system: An agent-based model applied to the city of Lisbon, Portugal. *International Journal of Transportation Science and Technology*. <https://doi.org/10.1016/j.ijtst.2017.05.005>.
- Ma, T.-Y., Rasulkhani, S., Chow, J. Y. J., & Klein, S. (2019). A dynamic ridesharing dispatch and idle vehicle repositioning strategy with integrated transit transfers. *Transportation Research Part E: Logistics and Transportation Review*, 128, 417-442. <https://doi.org/10.1016/j.tre.2019.07.002>.
- Mamun, S. (2011). Public transit accessibility and need indices: approaches for measuring service gap.
- Maxwell, J. A. (2012). *Qualitative Research Design: An Interactive Approach*. Sage Publications.
- May AD (1991) Integrated transport strategies: A new approach to urban transport policy formulation in the UK. *Transport Reviews* 11(3).
- Merlin, L. A., Singer, M., & Levine, J. (2021). Influences on transit ridership and transit accessibility in US urban areas. *Transportation Research Part A: Policy and Practice*, 150, 63-73.
- Mohiuddin, H. (2021). Planning for the first and last mile: A review of practices at selected transit agencies in the United States. *Sustainability*, 13(4), 2222
- Mokhtarian, M. N. (2011). A new fuzzy weighted average (FWA) method based on left and right scores: An application for determining a suitable location for a gas oil station. *Computers & Mathematics With Applications*, 61(10), 3136-3145.
- Moniruzzaman, M., & Páez, A. (2012). Accessibility to transit, by transit, and mode share: application of a logistic model with spatial filters. *Journal of Transport Geography*, 24, 198-205.

- Montgomery County Department of Transportation. (2020). "Ride On Flex Microtransit Performance Assessment." 2020. Accessed April 2023. <https://www.montgomerycountymd.gov/dot-transit/flex/>
- Murray, A. T., & Davis, R. (2001). Equity in regional service provision. *Journal of Regional Science*, 41(4), 557-600.
- Ocalir-Akunal, E. V. (2016). Decision support systems in transport planning. *Procedia Engineering*, 161, 1119-1126.
- Pena, J., Nápoles, G., & Salgueiro, Y. (2020). Explicit methods for attribute weighting in multi-attribute decision-making: a review study. *Artificial Intelligence Review*, 53, 3127-3152.
- Polzin, S. E., Pendyala, R. M., & Navari, S. (2002). Development of time-of-day-based transit accessibility analysis tool. *Transportation Research Record*, 1799(1), 35-41.
- Quade, I. P. B. (2003). TCRP Report 100: Transit Capacity and Quality of Service Manual. *Transportation Research Board of the National Academies*.
- Rauws, W. (2017). Embracing uncertainty without abandoning planning: Exploring an adaptive planning approach for guiding urban transformations. *DisP-The Planning Review*, 53(1), 32-45.
- Ryus, P. (2003). A summary of TCRP report 88: A guidebook for developing a transit performance-measurement system. *TCRP Research Results Digest*, (56).
- Saaty, T. L. (2008). Decision making with the analytic hierarchy process. *International Journal of Services Sciences*, 1(1), 83-98.
- Saaty, T. L. 1980, *The Analytical Hierarchy Process: Planning, Priority Setting, Resource Allocation*. McGraw-Hill International Book Co., London, England.
- Schwieterman, J. P., Livingston, M., & Van Der Slot, S. (2018). Partners in transit: A review of partnerships between transportation network companies and public agencies in the United States.
- Sevgi, E., Kaveh, F. S., Amir, N., Alibi, S., Gerrit, K., (2022). Prince George's County Microtransit Feasibility Study Final Report.
- SHAHEEN, S. & COHEN, A. 2018. Shared ride services in North America: definitions, impacts, and the future of pooling. *Transport Reviews*, 1-16.
- Shakir, M. (2002). The selection of case studies: strategies and their applications to IS implementation case studies.
- Sharma, G., & Patil, G. R. (2021). Public transit accessibility approach to understand the equity for public healthcare services: A case study of Greater Mumbai. *Journal of Transport Geography*, 94, 103123.
- Shim, J. P., Warkentin, M., Courtney, J. F., Power, D. J., Sharda, R., & Carlsson, C. (2002). Past, present, and future decision support technology. *Decision Support Systems*, 33(2), 111-126.
- Soria, J., Etzioni, S., Shifan, Y., Stathopoulos, A., & Ben-Elia, E. (2022). Microtransit adoption in the wake of the COVID-19 pandemic: evidence from a choice experiment with transit and car commuters. *arXiv preprint arXiv:2204.01974*.
- Rossetti, T., Broaddus, A., Ruhl, M., & Daziano, R. (2023). Commuter preferences for a first-mile/last-mile microtransit service in the United States. *Transportation Research Part A: Policy and Practice*, 167, 103549
- Steiner, R. L., Srinivasan, S., Mohebbi, M. M., Patni, S., Suarez, J., Krinos, L., & Rummler, J. (2021). Evaluation of East Gainesville's Microtransit Mobility Project.
- Taylor, B. D., and E. A. Morris (2015). Public transportation objectives and rider demographics: are transit's priorities poor public policy? *Transportation* 42(2), 347-367.
- The Incremental Model of Decision Making. (2017, June 19). Retrieved from <https://study.com/academy/lesson/the-incremental-model-of-decision-making.html>.
- The U.S. Department of Transportation (2021). *ITS Research Emerging and Enabling Technologies*. Retrieved from

[https://www.its.dot.gov/research\\_areas/emerging\\_tech.htm](https://www.its.dot.gov/research_areas/emerging_tech.htm). Accessed on 3/19/2021.

WMATA. (2021). "On-demand Transit." 2021. Accessed, March 2023.

Wei, R., Golub, A., Wang, L., & Cova, T. (2018). Evaluating and Enhancing Public Transit Systems for Operational Efficiency and Access Equity.

Westervelt, M., Huang, E., Schank, J., Borgman, N., Fuhrer, T., Peppard, C., & Narula-Woods, R. (2018). UpRouted: Exploring Microtransit in the United States.

Wilbur, M., Coursey, M., Koirala, P., Al-Quran, Z., Pugliese, P., & Dubey, A. (2023, May). Mobility-On-Demand Transportation: A System for Microtransit and Paratransit Operations. In *Proceedings of the ACM/IEEE 14th International Conference on Cyber-Physical Systems (with CPS-IoT Week 2023)* (pp. 260-261).

Wu, T., Li, M., & Zhou, Y. (2023). Measuring Metro Accessibility: An Exploratory Study of Wuhan Based on Multi-Source Urban Data. *ISPRS International Journal of Geo-Information*, 12(1), 18.

Xing, Y., Pike, S., Pourrahmani, E., Handy, S., & Wang, Y. (2022). Exploring the Consumer Market of Microtransit Services in the Sacramento Area, California.

Xu, Z. (2015). *Uncertain multi-attribute decision making: Methods and Applications*. Springer

Xu, Z. (2008). On multi-period multi-attribute decision making. *Knowledge-Based Systems*, 21(2), 164-171

Yeh, C. H. (2002). A problem-based selection of multi-attribute decision-making methods. *International Transactions in Operational Research*, 9(2), 169-181

Yin Robert, K. (1994). Case study research: Design and methods. *Sage Publications*.

Yoon, K. P., & Hwang, C. L. (1995). *Multiple attribute decision making: an introduction*. Sage Publications.

Zanakis, S. H., Solomon, A., Wishart, N., & Dublisch, S. (1998). Multi-attribute decision making: A simulation comparison of select methods. *European Journal of Operational Research*, 107(3), 507-529.

Zayat, W., Kilic, H. S., Yalcin, A. S., Zaim, S., & Delen, D. (2023). Application of MADM methods in Industry 4.0: A literature review. *Computers & Industrial Engineering*, 109075.

Zhang, T., Dong, S., Zeng, Z., & Li, J. (2018). Quantifying multi-modal public transit accessibility for large metropolitan areas: a time-dependent reliability modeling approach. *International Journal of Geographical Information Science*, 32(8), 1649-1676.

Zolfani, S. H., Maknoon, R., & Zavadskas, E. K. (2016). MADM and futures studies; a necessity. In *Conference: 9th International Scientific Conference "Business and Management*.

The U.S. Department of Transportation (2021). *ITS Research Emerging and Enabling Technologies*. Retrieved from

[https://www.its.dot.gov/research\\_areas/emerging\\_tech.htm](https://www.its.dot.gov/research_areas/emerging_tech.htm). Accessed on 3/19/2021.

## 5 Conclusion

This research aimed to examine the impact of technological advancements on public transportation, with a particular emphasis on paratransit and demand-responsive modes. The research followed a socio-technical approach with a specific focus on the implementation of technology. This chapter provides a summary of the main findings that address the research questions. The research contributions, which aim to enhance the understanding of how technological advancements shape public transportation and the implementation of communication and information technologies, are also discussed. The recommendations are directed toward practitioners, policymakers, and transit agencies. Finally, the limitations of the research are acknowledged, and potential future work is identified.

This three-paper dissertation delved into various aspects of transportation technological advancements in the transit domain. This included an in-depth literature review of real-time dynamic dispatching and scheduling, on-demand transit adoption, and measuring microtransit accessibility using a multi-attribute decision-making framework. These topics relate to the operational, planning, and policy challenges municipalities and transit agencies face in adopting and implementing these new technological systems in cities across the United States. The findings from Chapters 2, 3, and 4 are summarized below.

## 5.1 Main Findings and Contributions

This section summarizes the research gaps, questions, and contributions.

*Table 26 Research Gaps, Key Questions, and Findings and Contributions*

<b>Research Needs</b>	<b>Chapter</b>	<b>Research Questions</b>	<b>Findings &amp; Contributions</b>
<p>It is essential to conduct more research on Real-Time Dynamic Dispatching and Scheduling (RT-DDS) to address paratransit service problems and provide a more flexible service. Several studies have confirmed this need, yet there is still a lack of detailed discussion on how these technologies have evolved and can be used to bridge the gap in paratransit service. A study by Butler et al. (2021) broadly identified these challenges. USDOT recognizes the need for new institutional models to accelerate technology adoption. They promote exploratory research into emerging technology solutions across government, academia, and the private sector.</p>	2	<ol style="list-style-type: none"> <li>1. What are the current models, practices, and approaches used for RT-DDS adoption in paratransit?</li> <li>2. What types of RT-DDS operating systems are available?</li> <li>3. What are the benefits and functionalities of RT-DDS system adoption in paratransit?</li> </ol>	<p>This research adds to the existing literature and provides new insights into adopting real-time dynamic dispatching and scheduling technologies in paratransit. This study builds knowledge about on-demand paratransit systems by discussing technology adoption through an implementation lens. It helps managers understand how to apply RT-DDS to improve service design and outcomes for paratransit and demand-responsive transit.</p> <p>This research finds a growing trend among transit agencies and municipalities to use Real-Time Dynamic Dispatching and Scheduling (RT-DDS) technology systems for paratransit services, including improved on-demand transit. Several studies, including Weinreich et al. (2020) and Volinski (2019), support this finding.</p> <p>This research improves our understanding of RT-DDS technologies and their unique opportunities and adoption challenges that may manifest when these technological systems are implemented without clear business objectives.</p>
<p>Planning and policy practitioners struggle to measure on-demand transit</p>	3	<ol style="list-style-type: none"> <li>1. How does ODT improve transit outcomes?</li> </ol>	<p>On-demand transit (ODT) services are preferred over traditional public transit, such as paratransit, due to their</p>

<p>performance. As demand for these services increases, so does the need for relevant knowledge.</p> <p>Most literature reviews on mobility-on-demand models and definitions primarily discuss technology features. However, only a few studies compare their performance outcomes with paratransit services. Researchers have discussed on-demand transit performance in terms of service reliability, flexibility, and operating costs of shared mobility. Nevertheless, it is crucial to have a comprehensive discussion of the performance impacts of ODT services compared to paratransit.</p>		<ol style="list-style-type: none"> <li>2. What are the performance outcomes regarding ridership, on-time performance, and operating costs to the local agency providing ODT services?</li> <li>3. What are the technological features of on-demand transit services, and how do they impact the performance outcomes of on-demand transit services?</li> <li>4. What are the associations between on-demand transit performance and paratransit?</li> </ol>	<p>flexibility and higher level of reliability. This research found that ODT services have improved transit outcomes in the studied area.</p> <p>Case studies of successful ODT deployment in the Washington DC region, including Prince George’s County, Montgomery County, and Washington DC, were examined to suggest inputs for planners and policymakers to consider in assessing ODT performance outcomes.</p> <p>The study results indicate that the performance outcomes of ODT vary between agencies. However, these services are crucial in providing accessible transportation coverage to underserved communities.</p>
<p>Measuring the accessibility and availability of microtransit is crucial for predicting ridership, planning, and assessing service quality, and allocating resources. However, policymakers often face challenges in implementing and operating a microtransit system due to institutional, operational, and financial limitations. Therefore, it is essential to develop suitable measurement</p>	<p>4</p>	<ol style="list-style-type: none"> <li>1. How do practitioners think about microtransit?</li> <li>2. To what extent does an organization use multi-attribute decision-making techniques to support decisions on microtransit adoption to increase transit accessibility, and how do these relationships impact microtransit accessibility?</li> </ol>	<p>This study adds to the current body of literature on microtransit accessibility by identifying, categorizing, and integrating essential concepts related to this topic. Additionally, it addresses gaps in the literature by presenting components and steps that can aid in evaluating microtransit accessibility. This framework will help make informed decisions regarding microtransit planning and service design.</p> <p>The study proposes a multi-attribute decision-making approach for evaluating microtransit accessibility. A</p>

<p>approaches to help design and evaluate microtransit planning more effectively, leading to better adoption and implementation of such systems.</p>			<p>three-step MADM approach that includes the microtransit propensity index, level of service measures, and weighted average scoring to analyze and rank related attributes.</p> <p>The research indicates that the microtransit propensity is mid-high for Rockville, mid-low for Wheaton-Glenmont zones in Montgomery County, and low for Oxon Hill in Prince George's County.</p>
--	--	--	--

## **5.2 Real-Time Dynamic Dispatching and Scheduling in Paratransit: A Literature Review**

Previous research on transportation technology changes in transit has highlighted the need for a systematic review of factors that may impact the adoption and implementation of technology in paratransit. Furthermore, few studies have explored the impact of technology adoption in paratransit on performance outcomes for on-demand transit and using multi-attribute decision-making methods to analyze microtransit accessibility. Chapter 2 provides a literature review of real-time dynamic dispatching and scheduling (RT-DDS) in paratransit. The chapter explores and attempts to answer the following questions.

### **1. What are the current models, practices, and approaches used for RT-DDS adoption in paratransit?**

Chapter 2 offers a thorough analysis of paratransit, focusing on its technical sophistication and the current state of practice. It provides valuable insights into the challenges of implementing advanced paratransit systems. It examines the models, practices, and approaches for adopting Real-Time Demand-Responsive Dispatching Systems (RT-DDS) in paratransit. The chapter identifies three primary RT-DDS adoption models – Software-as-a-Service (SaaS), Transportation-as-a-Service (TaaS), and Mobility-as-a-Service (MaaS) – as well as a fourth contractual partnership model that is often utilized in conjunction with any of the three principal adoption models. Furthermore, Chapter 2 explores the RT-DDS practices and application approaches encompassing the entire range of transit software applications. This includes bus services, traditional demand-responsive paratransit, and emerging on-demand paratransit modes such as on-demand transit, microtransit, partnerships with TNC/Ridesharing, and commingling.

### **2. What types of RT-DDS operating systems are available?**

Chapter 2 identified three types of RT-DDS operating systems based on trip and match type and provided examples. The following three types of RT-DDS were noted and discussed. First are the express or direct trips for a single rider and a match of one driver and one rider, such as for a single taxi trip using UberX or Lyft. Second is ridesharing/ridesplitting trips that match one driver and multiple passengers, such as Uber Pool, paratransit, microtransit, and on-demand shuttle. Third is a hybrid of express and ride-splitting matched by any combination of one driver to one rider or multiple passengers, such as an on-demand shuttle.

### **3. What are the benefits and functionalities of RT-DDS system adoption in paratransit?**

Chapter 2 discusses the main benefits of RT-DDS. These include the ability of RT-DDS to address any specific dial-a-ride problem (DARP), which is often intended to minimize costs by maximizing ridesharing opportunities. Ride-splitting can serve more passengers with limited resources while matching one passenger to one driver can provide more flexibility and reliability and increase service quality. Addressing DARP challenges will allow transit agencies to expand service options such as microtransit, ridesharing, and on-demand paratransit, which can have significant benefits for inclusion and social impact, especially for zero-vehicle households or individuals who cannot use private transportation due to lower incomes or disabilities. Chapter 2 also discusses RT-DDS applications and functionalities with the main emphasis on the embedded algorithm that supports decision-making capabilities, allowing for on-demand trip requests and vehicle matching that occur in real time. The chapter further highlights the main objective of RT-DDS adoption, which is to reduce operating costs, the total user ride time (URT), and the time riders spend on buses.

## **On-Demand Transit: Defining Performance Attributes and Service Outcomes**

Chapter 3 focuses on the technology systems used in on-demand services in the Washington DC region. It examines explicitly three on-demand transit services – DC Neighborhood Connect, Ride On Flex, and PGC Link in Prince George’s County, Maryland. The chapter analyzes the performance outcomes of these services and explores the causal linkages between on-demand transit performance and paratransit. The study examines and summarizes the impact of real-time dynamic dispatching and scheduling technology on transit agencies’ adoption of on-demand transit modes based on interviews with local officials and transit industry professionals. The study aims to understand the performance outcomes related to on-time performance, ridership, and operating costs of on-demand transit services in the region. It finds that innovative on-demand transit projects focus on strengthening existing public transit systems and services. Chapter 3 seeks to provide answers to the following questions.

### **1. How does ODT improve transit outcomes?**

Chapter 3 discusses how ODT improves transit outcomes using three case examples in the Washington DC region: PGC Link, Ride On Flex, and DC Neighborhood Connect. In all cases, ODT implementation and performance outcomes have been driven primarily by the need to promote accessible transit options to address service equity and fill gaps in transit coverage. The findings suggest that ODT adoption can help alleviate and address performance deficiencies and issues with paratransit or fixed-route transit to improve reliability, coverage, and accessibility. It elaborated on how ODT implementation and performance outcomes have been driven primarily by the need to enhance the availability of accessible transit options to address service equity and fill gaps in transit coverage.

## **5.3 On-Demand Transit (ODT): An Exploratory Case Study of Washington DC's Efforts to Improve Service Outcomes**

Chapter 3 discusses the results from an online survey and shows data on performance outcomes on ridership, on-time performance, and operating costs. The study finds a strong connection between on-time performance (wait time and ride time), which increased ridership can significantly impact. Operating costs per passenger trip are higher than fixed route buses. Local officials emphasize equity, accessibility, and connections to opportunities when implementing ODT services, which are linked to reducing wait times and increasing ridership.

### **1. What are the technological features of on-demand transit services, and how do they impact the performance outcomes of on-demand transit services?**

Chapter 3 discusses on-demand transit technological features such as real-time dynamic routing technology for scheduling trips, ridesharing, and on-demand ride services with similar origin-destination pairing. On-demand transit services are powered by digital technology innovations and platforms that use algorithms to direct vehicles (including navigation tools, ride-sharing apps, delivery, and ride services) and autonomous vehicles. By leveraging new and integrated technology solutions, on-demand paratransit can help cover the last and first mile between public transport stations, improve ODT's overall efficiency and service quality, connect commuters to their final destinations, and progressively reduce demand for privately owned vehicles. Furthermore, Chapter 3 discusses the commingling or mixed operations of paratransit and ODT. Commingling is an operational practice of using the same pool of resources, such as drivers, vehicles, and information technology systems, to support paratransit and on-demand transit services, such as flex-routing, microtransit, and on-demand shuttle services. The research suggests that transit planners, transit managers, and policy practitioners must take a holistic view toward improving ODT's overall efficiency and service quality and connecting people to their points of interest when proposing.

## 5.4 Multi-Attribute Decision-Making Approach to Measuring Microtransit Accessibility

Chapter 4 presents the results of evaluating the accessibility of microtransit in Prince George's and Montgomery Counties in Maryland, using a multi-attribute decision-making (MADM) approach. Three methods were combined and weighted to create a composite measure. These methods were the Microtransit Propensity Index (MPI), Level of Service (LOS), and Weighted Accessibility Score (WAS). This research focused on creating a comprehensive evaluation framework to assess microtransit accessibility.

### **1. How do accessibility factors impact decision-making in adopting microtransit?**

In Chapter 4, a proposed multi-attribute decision-making (MADM) approach for enhancing microtransit accessibility is outlined. The approach considers the LOS and MPI methods and the WAS hierarchical ranking approach. The chapter delves into a range of factors, including socioeconomic and demographic characteristics of zone residents, spatial geography, employment, population density, household income, and percentage of zero-vehicle households. MADM offers a framework that could be used to support microtransit planning and service design. This study provides municipalities and transit agencies with a three-step methodology for building scenarios and making informed decisions about microtransit accessibility compared to the many proprietary simulation tools for microtransit planning and service design. Findings from this study reveal that attributes such as low-income populations with lower job accessibility, longer access time to jobs, and zero-vehicle households were factored in the planning and design simulation of the service area. Nevertheless, similar microtransit projects, like PGC Link and Ride-On Flex, exhibit different outcomes when evaluated using a multi-attribute decision-making (MADM) approach.

### **2. To what extent does an organization use multi-attribute decision-making techniques to support decisions on microtransit adoption to increase transit accessibility, and how do these relationships impact microtransit accessibility?**

Chapter 4 introduces a new multi-attribute decision-making approach to evaluate microtransit accessibility. Previous studies have utilized the MPI method to assess the feasibility of microtransit services. Accessibility associated with the connection between a place of origin and destination is often mentioned as a microtransit implementation goal, but it is hardly measured or tracked. However, third-party mobility providers like Via, RideCo, Uber, and Lyft are increasingly being relied upon by municipalities for data analysis and sharing microtransit service design and propensity. The microtransit Propensity Index (MPI) is used by these vendors, along with transit agencies and providers, to determine microtransit suitability. When employed alone without considering other factors and techniques, it may not be easy to classify MPI as a multi-attribute decision-making method. Furthermore, accessibility measures to POIs and jobs by census block, which identify socio-economic attributes of accessibility such as demographic, coverage, and level of service attributes, have been given less emphasis by organizations as an essential component of MADM. More needs to be done in prioritizing accessibility benefits not only individuals but can also significantly impact businesses.

## **5.5 Main Findings and Summary**

This study aims to investigate the planning practices and policies associated with technology changes in transit and how they can be effectively implemented to meet the practical travel requirements of commuters. The research aims to improve our understanding of real-time dynamic dispatching and scheduling technology systems and their potential application in paratransit through detailed analysis and insights.

Chapters 2, 3, and 4 examine the adoption of technology in paratransit and transit, highlighting the shift from focusing on the technology itself to the outcomes of its application. Recent studies have emphasized the importance of implementation processes, business and

organizational impacts, and people, including the challenges institutional actors and mobility stakeholders face in providing transit services. In addition, there is a growing emphasis on addressing systemic issues and barriers to public transit, such as the lack of accessible options. Accessibility in transport planning refers to the ease of reaching and interacting with destinations or activities within a defined area, such as a city or county. New platform technology systems can potentially address many of the accessibility issues we face today, such as the lack of accessible options. The COVID-19 outbreak accelerated the development and execution of automation technologies like real-time dynamic dispatching and scheduling. These have proven advantageous for growing on-demand transit and mobility services throughout urban and suburban areas in the US. Innovations in information and communication technologies have laid the groundwork for dynamic capabilities, empowering both transit organizations and private mobility providers to reconsider and redefine pre-pandemic models by exchanging obsolete procedures with modernized and enhanced systems.

The main contribution from Chapter 4 is the proposed formulation of a three-step MADM approach to measure microtransit accessibility, including simple service components like ease of access, service hours, and days of service. The three models used to calculate micro transit accessibility and impacts on planning and decision-making processes used different assumptions, limiting standardized values to compare accessibility attributes. Additionally, the assumption that microtransit adoption offers shorter travel times and curb-to-curb access in areas of limited access to transit is inherently beneficial and requires further research.

This study introduces a multi-level decision-making framework for evaluating public transit service performance. The study sheds light on the impact of transportation technology on planning,

policy, and decision-making processes. However, several issues and limitations need further discussion.

## **5.6 Limitations and Future Research**

The primary objective of this study was to investigate the implementation and adoption processes of evolving technologies in paratransit, a demand-responsive form of transit. To achieve this objective, the study employed a mixed approach, including a literature review and interviews, to reveal the contextual factors of complex technology adoption and implementation processes. The study findings provide a methodological contribution to understanding the interplay between technology, planning, and policy in different settings.

However, the study encountered several limitations. Firstly, transportation technology is rapidly evolving, and its practices and approaches are changing quickly. Thus, this study's findings may not apply to some US paratransit systems because the data were based on a highly urbanized setting. Secondly, there is a need to develop a standard method for assessing operational costs resulting from RT-DDS adoption compared to traditional paratransit. Fourthly, the COVID-19 pandemic significantly impacted the current and future transportation outlook, affecting the study findings.

Chapter 3 of the study had some limitations regarding the generalizability of insights. Future studies could examine ODT trip-level data from agencies to provide more detailed insights. Additionally, aligning the data collected by this research with publicly available data was a challenging task. However, there are opportunities for future work to expand the scope of this analysis to incorporate additional trip-level data. The broader use of complementary data sources could have lent more credibility to the study and provided a more nuanced understanding of the problem.

## 5.7 Future Work

Over the years, transit agencies have encountered various challenges due to the growth in demand. The COVID-19 pandemic temporarily relieved demand concerns, as Ashour et al. (2021) and Wilbur et al. (2023) indicated. With the introduction of RT-DDS for on-demand paratransit, an innovative mobility system that presents various research opportunities, transit agencies can now offer riders more flexible and alternative mobility options. However, to ensure that services remain equitable, it is essential to promptly address any gaps and potential challenges that may arise because of adopting new technologies. Future studies could examine the operational and organizational impacts of RT-DDS adoption and emerging business models for paratransit.

Transit agencies have faced numerous challenges related to demand growth over the years. The COVID-19 pandemic temporarily reduced demand concerns, as Ashour et al. (2021) and Wilbur et al. (2023) noted. Adopting RT-DDS for on-demand paratransit is an emerging mobility system with many research opportunities. As transit agencies adopt new technologies to provide riders with more flexible and alternative mobility options, addressing gaps and foreseeable challenges is crucial to maintain equitable services promptly. On-demand transit (ODT) is an innovative way to provide mobility services. It is essential to improve the design and delivery of ODT services and develop standard ways to measure the performance of services. Future research should focus on optimizing ODT productivity and performance, particularly during off-peak hours. However, implementing ODT services poses challenges, such as developing effective business models and procurement tools that address data sharing between public and private partners. Further research should explore emerging business models to deepen our understanding of ODT as a viable form of technology-enabled transit option.

## 5.8 References

- Ashour, L. A., Dannenberg, A. L., Shen, Q., Fang, X., & Wang, Y. (2021). Paratransit services for people with disabilities in the Seattle region during the COVID-19 pandemic: Lessons for recovery planning. *Journal of Transport & Health, 22*, 101115.
- Wilbur, M., Coursey, M., Koirala, P., Al-Quran, Z., Pugliese, P., & Dubey, A. (2023, May). Mobility-On-Demand Transportation: A System for Microtransit and Paratransit Operations. In *Proceedings of the ACM/IEEE 14th International Conference on Cyber-Physical Systems (with CPS-IoT Week 2023)* (pp. 260-261).

# Appendices

## Appendix A: Survey Questions

### Draft Letter to Survey Participants

IRB# 22-164

Dear Participant:

Thank you for taking the survey! I am a doctoral candidate at Virginia Tech. I am conducting this research to develop a greater understanding of on-demand transit. The survey questions include on-demand service goals, performance outcomes, agency, and demographic information. This survey will take approximately 10 minutes to complete.

Obtaining feedback from transit professionals is vital to this research.

There are no foreseeable risks associated with your participation in this survey. Completing this survey is voluntary. However, suppose you feel uncomfortable answering any questions. In that case, you may skip any questions you do not wish to respond to for any reason and can withdraw from the survey at any time by exiting the survey window.

Your survey responses will be strictly confidential, and data from this research will be reported only in the aggregate. Your information will be coded and will remain confidential and secure. Your identity will be confidential.

If you have questions about the survey or the procedures at any time, you may contact Efon Epanty by email at [efon@vt.edu](mailto:efon@vt.edu). You are not waiving any legal claims, rights, or remedies because of your participation in this research study. If you have questions regarding your rights as a research participant, contact the Virginia Tech HRPP Office at 540-231-3732 ([irb@vt.edu](mailto:irb@vt.edu)).

Please reference study number 22-164 when contacting anyone about this project. Thank you very much for your time and support. Please start with the survey now by clicking on the Continue button below.

Note: When the survey is taken on a resized browser rather than full screen, some elements of the survey, including the "next" button, are not visible. Please use full-screen mode. This note can be ignored if taking the mobile version of the survey.

Electronic consent: By selecting "I agree," you agree to participate in this survey; you agree to participate in this survey, affirming that you are giving consent for Virginia Tech to use your confidential responses in this study.

1. I agree
2. I disagree

## Survey Questions

For this survey, on-demand transit refers to tech-enabled shared ride service or digital platform technologies for flexible public transit service that allows for real-time trip requests, matching riders and drivers, point-to-point routing, paying fares, and tracking the entire trip or journey in real-time using a single app.<sup>1</sup> Please indicate the type of geographic area your organization serves or provides transit services to.

1. Rural
2. Urban
3. Mixed Urban/Rural
4. Suburban
5. NA

2. Please indicate the category that best describes your agency

1. Public Agency
2. State Transit Agency
3. Transit Authority
4. Transit District
5. Local or Municipal Transit Agency
6. For-Profit Organization
7. Not-for-Profit
8. Human Services
9. Academia
10. Consultant
11. Other: Please Specify \_\_\_\_\_

3. What is the approximate size of your paratransit bus fleet (please consider all vehicle types)?

1. Under 50
2. 51-100
3. 101-200
4. 201-300
5. Above 300
6. N/A

4. Please rank (1-highest to 5-lowest) the following in order of top ridership destinations for your agency's on-demand service:(Leave blank if it does not apply)

- School/Education \_\_\_\_\_
- Shopping/Groceries \_\_\_\_\_
- Medical/Pharmacy \_\_\_\_\_
- Work/Job-Related \_\_\_\_\_
- Activity Centers \_\_\_\_\_

5. What state do you work in?

6. What paratransit service types does your agency provide or operate? Please select all that apply

1. ADA Paratransit
2. Supplemental Paratransit
3. On-demand Paratransit
4. Senior Transportation
5. Medicaid NEMT
6. Microtransit (i.e., flex route, first-and last-mile, etc.)
7. TNCs Partnerships
8. Taxi Service
9. Services for Disabled Veterans
10. Human Service Transportation
11. Other: Please Specify \_\_\_\_\_
12. N/A

7. Please indicate if on-demand service is provided using paratransit vehicles and drivers. (Leave blank if it does not apply)

	Yes	No	Don't Know
Vehicles	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Drivers	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

8. Does your on-demand service and paratransit dispatching and scheduling system use the same technology/platform?

1. Yes
2. No
3. Don't Know

9. Which of the following does your organization use to provide on-demand trips? (Please select all the apply)

1. TNCs (partnership with Uber/Lyft)
2. Taxi
3. Van
4. Cutaway
5. Other: Please Specify \_\_\_\_\_

10. Which of the following categories best describes the function you work in?

1. Administration
2. Operations Management
3. Data/Technology
4. Dispatching/Scheduling
5. Fleet/Facility Maintenance
6. Field Supervision
7. Finance/Budget
8. Safety/Risk/Training
9. Transit Service Planning
10. Other: Please Specify \_\_\_\_\_

11. For how many years have you been in the transportation industry?

1. 5 years or less
2. 6-10 years
3. 11 or more years
4. NA

12. To what extent does your organization use the following established digital technologies to measure, manage, and report on transit performance and service impacts? (1-Not used at all - 5-Extensively used; Don't know)

	1-Not Used at all	2-Seldomly used	3-About half the time	4-Often	5-Extensively used	Don't Know
Business Management Systems (e.g., ERP, CRM)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Business Intelligence (e.g., Power BI, Cognos BI, Tableau)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
GIS Data Visualization Tools	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Transit Planning/Dash Dashboards (e.g., Swiftly, Remix)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Excel Spreadsheet Tools	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Transit Technology Systems (e.g., Hastus, Trapeze)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Third-Party Apps/Platforms (Via, RideCo, Lyft, Uber)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Others: Please Specify	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

13. To what extent does your organization use the following transit-related variables for decision-making? (1-Not used at

all - 5-Extensively used; Don't know)

	1-Not Used at all	2-Seldomly used	3-About half the time	4-Often	5-Extensively used	Don't Know
On-time performance	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Reliability (missed trips, delays, wait, and travel time)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ridership	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Productivity	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Operating cost	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Customer complaints	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Coverage (easy access to key destinations)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

14. Considering paratransit service ONLY, how satisfied are you with each of the following aspects of that service? (1-Very dissatisfied - 5-Very satisfied; Don't know)

	1-Very dissatisfied	2-Not satisfied	3-Neutral	4-Satisfied	5-Very satisfied	Don't Know
On-time performance	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Reliability (missed trips, delays, wait, and travel time)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ridership	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Productivity	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Operating cost	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Customer complaints	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Coverage (easy access to key destinations)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

15. Considering on-demand service ONLY, how satisfied are you with each of the following aspects of that service? (1-Very dissatisfied - 5-Very satisfied; Don't know)

	1-Very dissatisfied	2-Not satisfied	3-Neutral	4-Satisfied	5-Very satisfied	Don't Know
On-time performance	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Reliability (missed trips, delays, wait, and travel time)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ridership	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Productivity	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Operating cost	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Customer complaints	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Coverage (easy access to key destinations)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

16. Comparing paratransit and on-demand service outcomes, which one performs the best? (Leave blank if it does not apply)

	On-demand	Paratransit	Don't Know
On-time performance	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Reliability (missed trips, delays, wait, and travel time)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ridership	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Productivity	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Operating cost	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Customer complaints	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Coverage (easy access to key destinations)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

17. Importance [Not Important, Very Important]

	1	2	3	4	5	N/A
Faster trips with fewer stops to destinations	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Reduce operation cost compared to ADA paratransit.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Fares are affordable to riders.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Flexible: Need to be there when riders need it	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Stop at or near critical destinations	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Service is spatially available, and destinations are reachable	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
On-time pickup and drop-off when riders need it	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
A safe system for all riders and drivers	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Satisfaction [Not Satisfied, Very Satisfied]

	1	2	3	4	5	N/A
Faster trips with fewer stops to destinations	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Reduce operation cost compared to ADA paratransit	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Fares are affordable to riders	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Flexible: Need to be there when riders need it	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Stop at or near key destinations	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Service is spatially available, and destinations are reachable	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
On-time pickup and drop-off when riders need it	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
A safe system for all riders and drivers	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

18. Please compare the level of transit services provided before the pandemic to the services offered now. Is the current level of services greater than, less than, or the same as it was before the pandemic?

	Increased	Same	Decreased	Don't Know
On-demand	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Paratransit	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

19. Has your agency expanded on-demand services since 2020?

1. Yes
2. No
3. Don't Apply

**Demographic Information**

20. With which gender do you identify?

1. Female
2. Male
3. Non-binary
4. Prefer not to say
5. Other: Please Specify

21. What is your race or ethnicity?

1. American Indian or Alaskan Native
2. Asian
3. Black or African American
4. Latino or Hispanic
5. White

6. Native Hawaiian or other pacific islanders
7. Multiple races
8. I prefer not to say
9. Don't know
10. Other: Please Specify

22. Please indicate your age group.

1. <19
2. 20-29
3. 30-39
4. 40-49
5. 50-59
6. 60-69
7. > 70

23. What is the highest level of education you have completed or the highest degree you have received?

1. High school
2. Some college
3. Trade/vocational/technical
4. Associates
5. Bachelors
6. Masters
7. Professional
8. Doctorate
9. Other: Please Specify \_\_\_\_\_

Thank you for your participation. Please enter your email address below if you are interested in a follow-up interview on your on-demand transit service.

# Appendix B: Semi-Structured Interview Guide & Consent Forms

Appendix B includes the draft interview question guide and Virginia Tech consent form.

## Semi-structured Interview Guide

### Background Information

Candidate Name:

Position Title:

Contact:

Transit Agency:

Location/Address:

Date of Interview

Interview Start & End Times:

### Introduction from me:

1. Greetings: thank you for taking the time to talk to me.
  - Introduce myself. Start by stating that I am a PhD student at Virginia Tech. Provide information on my background and areas of expertise.
2. Explain the purpose of the interview and briefly discuss the research goals and objectives.
  - Explain the purpose of this meeting and the interview process. Note how much time is allotted, the note-taking, and the opportunity for the applicant to ask questions.
3. Ask for consent to share anonymized findings (report) and full notes with the faculty.
  - **The information you have submitted will be published as a report; please indicate whether you would like to receive a copy. Yes or No**
  - **I understand that confidentiality and anonymity will be maintained and identifying me in any publications will not be possible. Yes or No**
  - **I understand that the information collected about me will be used to support other research in the future and may be shared anonymously with other researchers.**

### Discussion with the interviewee

### Interview Questions

1. *Can you discuss your agency's paratransit and on-demand transit (ODT) models?*
  - a. *Please tell me a little bit about your on-demand transit project.*
  - b. *Could you briefly describe the data types used in your group's planning and operational management?*
  - c. *How did you go about deciding on service design and performance requirements?*
  - d. *How can I find out more?*
  - e. *Follow-up data request. (Please see the chart below)*

	<b>Who is responsible?</b>
--	----------------------------

	<i>(in-house, contracted, broker, service provider/s, partnership w/TNCs)</i>			
<b>Service model</b>	<b>Vehicle</b>	<b>Reservation/ Booking</b>	<b>Scheduling</b>	<b>Dispatching</b>
Paratransit				
On-Demand Transit (ODT)				
Microtransit				
TNC				
Taxis				
Others: Specify				

**2. How do you think about microtransit accessibility?**

- a. How do you define accessibility?
- b. What factors or variables do you use to measure microtransit accessibility?
- c. How do you measure microtransit accessibility, or what are factors you consider when it comes to accessibility?
- d. Can you please talk a little about your service hours, days of service, span of service, and coverage in general?

**3. Tell me about what is being done to enhance microtransit accessibility.**

- a. Do you think microtransit will be expanded or changed in ways that will make more people use the service?
- b. Tell me about riders who use your service the most

**4. Do you use any software to help you with data management?**

- a. What are your thoughts on the causes of ODT or paratransit service gaps?
- b. What kinds of operational data do you have about paratransit and ODT performance?
- c. What are your thoughts on identifying gaps using operational data such as ridership, operating costs, and reliability –on-time performance and wait time?
- d. What are some strengths of the method(s)/practices you used? Follow-up data request. Operational performance data for paratransit and on-demand transit (ODT).

	<i>January 2019 to December 2021</i>	<b>Paratransit</b>	<b>ODT</b>
<b>a</b>	<b>Ridership</b>		
	Total monthly		
	Average weekly		
	Average trips per revenue mile		
<b>b</b>	<b>On-time performance (service reliability measured by the percentage of trips that arrived within their estimated arrival time).</b>		
	Average on-time performance (monthly)		
	Average missed trips (monthly)		
<b>c</b>	<b>Operating cost (Monthly)</b>		
	Total cost per trip		

	Average cost per trip		
	Average revenue hours		
	Average revenue miles		

5. **Can you discuss your operational objectives for implementing microtransit or on-demand transit (ODT)?**
6. **What are the key distinctions between paratransit, ODT passengers, and providers?**
7. **Do you have some thoughts on how your microtransit or ODT service model works? (For example, first and last-mile service model or coverage-based service model)**
8. **Do any of the following fit what your agency wanted to accomplish by implementing microtransit or ODT?**
  - *Provide transportation to areas previously underserved.*
  - *Drive economic growth by connecting people with more jobs.*
  - *Minimal long-term capital investment or risk.*
  - *Deliver a higher quality of service for a comparable cost to today's paratransit or related bus service.*
  - *Reduce manual intervention for dispatchers once trips are brought in-house.*
  - *Improve productivity through increased ridesharing.*
  - *Increase ridership with a convenient and tech-enabled experience.*
  - *Demonstrate the feasibility of coordinating services between multiple public and private providers.*
  - *Improve access to critical resources – such as healthcare, food, government, and regional transportation options.*
  - *Repurpose underperforming bus routes.*
9. **What goals has the flexibility of service achieved? (For example, increased access, reduced long wait times or headways, expanded the utility of transit, and reduced rider or passenger wait times by using dynamic routing technologies to match supply and demand).**
10. **Did your microtransit or ODT services experience any ridership growth (i.e., monthly completed) in 2019 and 2020? (Please provide your monthly ridership data for 2019 and 2020).**
11. **What are the average riders per vehicle hour, weekly ridership, wait time, cost per ride, and unique active riders for microtransit or ODT? (Please provide your microtransit/ODT data for 2019 and 2020).**
12. **What fundamental service changes have your agency implemented to increase efficiency while accommodating any increase in demand? (For example, the agency expanded its service hours in September 2020 to support increased demand or added a new service provider to reduce average wait and ride times).**
13. **Does your agency combine ODT and paratransit services?**

*Explain what commingling means: the practice of sharing resources, such as routing technologies, drivers, or vehicles between two modes of services – such as microtransit/ODT and paratransit service)*

**14. Have paratransit passengers shifted to the microtransit/ODT mode of transportation?**

**15. Paratransit or other dedicated operations by fleet and zone**

Examples to mention:

- Fleet and zone
- Number of existing zones
- Size of the existing zone
- Dedicated number of vehicles

**16. To what extent does your organization use multi-attribute decision-making techniques to support decisions on microtransit adoption to increase transit accessibility, and how do these relationships impact microtransit accessibility?**

**17. Please share any microtransit studies or technical analyses your agency has completed within 24 months.**

**18. I want to ask questions about your ODT service area and characteristics.**

Examples to mention:

**Sample Variable, Data, and Question Prompts.**

Variable		Question
Service Area Characteristics within Zone	Population	What is the population density?
	Jobs	What is the employment density?
	Land Use	What is the land use pattern?
	Zones	How many zones are in operation?
	Square miles	What is the square mile radius per zone?
Service Area Provision within the microtransit zone	First Mile-Last Mile	What are and how many FM-LM connections are served?
	Bus stops	Are the bus stops designated or virtual?
	Days of Service	How many days does your service operate?
	Service hours	What are the days and hours of operation?
	Wait times	How long is the wait between the vehicle request and the vehicle arrival?

Service standards	Performance measurements	What are the performance trends (ridership, operating cost- per hour/mile, on-time performance)?
	Measuring success	How is the program determined to be successful?
		Was the service used to reinstate or replace the FRB service?
Jobs	What is the employment density?	

## Wrap up

- ***I would appreciate your feedback on the impact of on-demand microtransit on improving transit service performance outcomes.***
  - Would you like to stay connected with me to help shape and develop the research
  - Provide email address and contact details.
  - Thank them for their time and say it was especially important for my understanding of your service.
- Encourage the interviewee to take the online survey
  - ***The link to the survey is below, and it says it will only take about 10 minutes to complete. Offer to share the survey link with the interviewee***
  - <https://virginiatech.questionpro.com/t/AWoESZvYwR>

## **Consent to Take Part in a Research Study**

Information Sheet for Participation in a Research Study

Title of Study: Evolving Technology Changes Shaping The Future of Transit

IRB# 22-164

Greetings:

You are invited to participate in this Virginia Tech graduate research project because you are a transportation professional. I am a graduate student at Virginia Tech, and we are conducting this research as part of my dissertation. This survey will take approximately 45 minutes to complete the interview. The semi-structured interview includes on-demand service goals, performance outcomes, and other operational topics.

There are no foreseeable risks associated with your participation in this interview. Completing this interview process is voluntary. However, suppose you feel uncomfortable answering any questions. In that case, you may skip any questions you do not wish to respond to for any reason and can withdraw from the survey at any time by exiting the survey window. We need to learn your opinions as transportation professionals.

Your survey responses will be strictly confidential, and data from this research will be reported only in the aggregate. Your information will be coded and will remain confidential and secure. Your identity will be confidential.

If you have questions about the survey or the procedures at any time, you may contact Efon Epanty at [efon@vt.edu](mailto:efon@vt.edu). You are not waiving any legal claims, rights, or remedies because of your participation in this research study. If you have questions regarding your rights as a research participant, contact the Virginia Tech HRPP Office at 540-231-3732 ([irb@vt.edu](mailto:irb@vt.edu)).

Please reference study number 22-164 when contacting anyone about this project. Thank you very much for your time and support. Please start with the survey now by clicking on the Continue button below.

**Note:**

When the survey is taken on a resized browser rather than full screen, some elements of the survey, including the "next" button, are not visible. Please use full-screen mode. This note can be ignored if taking the mobile version of the survey.

Electronic consent: By selecting "I agree," you agree to participate in this survey, affirming that you consent for Virginia Tech to use your confidential responses in this study. Click yes to begin or no to exit.

Yes

No



## Information Sheet for Participation in a Research Study

IRB# 22-164

Title of Study: Evolving Technology Changes Shaping The Future of Transit

You are invited to participate in a research study. This form includes information about the study and contact information if you have any questions.

I am a graduate student at Virginia Tech, and I am conducting this research as part of my coursework. I invite you to complete the **survey using this link**.

If you decide to participate in this study, you will complete a survey. As part of the study, you will be asked to complete an online survey. The survey asks about the perception of technology changes in transit and the potential impacts of technology adoption on employee performance and ease of use of technology.

The study should take approximately 10-15 minutes of your time.

We do not anticipate any risks from completing this study. You can choose whether to be in this study or not. If you volunteer to be in this study, you may withdraw at any time without consequences of any kind. You may also refuse to answer any questions you don't want to answer and remain in the study. The investigator may withdraw you from this research if circumstances arise that warrant doing so.

We will do our best to protect the confidentiality of the information we gather from you, but we cannot guarantee 100% confidentiality. Your responses are anonymous, so no one can associate your answers back to you. Please do not include your name or other identifying information in your responses that can identify you.

Thank you for considering this request. If you have any questions or concerns about the research, please feel free to contact Efon Epanty at [efon@vt.edu](mailto:efon@vt.edu). You are not waiving any legal claims, rights, or remedies because of your participation in this research study. If you have questions regarding your rights as a research participant, contact the Virginia Tech HRPP Office at 540-231-3732 ([irb@vt.edu](mailto:irb@vt.edu)).

If you would like to participate in this survey, click yes to begin or no to exit.

Yes

No