A SYSTEMATIC STAKEHOLDER-DRIVEN FRAMEWORK FOR EMPIRICAL CHARACTERIZATION AND PARAMETERIZATION OF HUMAN AGENTS FOR AGENT-BASED MODELING OF OLDER ADULTS' TRANSPORTATION

by

NILUFER ORAN GIBSON

DISSERTATION

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Supervising Committee:

Dr. Caroline C. Krejci, Supervising Professor

Dr. Shuchisnigdha Deb

Dr. Brian Huff

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DEDICATION

I dedicate this dissertation to my parents, my brother, and my husband.

I am forever grateful to my parents and my brother for their endless love, their immense support, and sacrifices for my education, well-being, and for me to be a well-rounded person. I am deeply grateful for my husband's unconditional love, his continuous effort to cheer me up, soothe me during long nights of work, and his encouragement to make me believe in myself.

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ABSTRACT

A SYSTEMATIC STAKEHOLDER-DRIVEN FRAMEWORK

FOR EMPIRICAL CHARACTERIZATION AND PARAMETERIZATION OF HUMAN AGENTS

FOR AGENT-BASED MODELING OF OLDER ADULTS' TRANSPORTATION

Nilufer Oran Gibson, Ph.D.

The University of Texas at Arlington, 2021

Supervising Professor: Caroline C. Krejci

Standard of living for health and well-being of oneself and of one's family is a human right. Vulnerable populations are incapable of maintaining an adequate standard of living due to several reasons, such as financial constraints, racial profiling, health conditions, aging, and the combination of these reasons. To alleviate their vulnerability, the most basic needs of the vulnerable populations must be met. Transportation is the essential link to the resources to address the basic needs of the vulnerable populations. Transportation solutions tailored for vulnerable populations to meet their basic needs have multiple dimensions that require the involvement of all government levels from federal to city, health institutions, non-profits, transportation providers, individual citizens, and many more.

This dissertation focuses on addressing the basic needs of older adults by improving their current transportation options and introducing a volunteer driver program. The impact of a volunteer driver program and the improvements of current transportation options on older adults' satisfaction levels is modeled and studied with agent-based modeling for Dallas, Texas. The results of this model suggested that community-dwelling older adults living in Dallas, Texas would benefit from a community-tailored volunteer driver program and that they are happier and more satisfied when riding with volunteer drivers in Dallas, Texas, compared to other transportation options, such as rideshare and bus service.

The main contribution of this dissertation is a systematic framework to empirically develop realistic agents and estimate agent parameters for agent-based modeling. This systematic framework sequences the Personas Concept, House of Quality, and PAPRIKA method via 1000minds software, respectively. This framework helps decision makers focus on the beneficiaries of the volunteer-driven programs and incorporate the decision makers' expertise in parameter estimation of the agents.

While the systematic framework is demonstrated with older adults in this dissertation, any research requiring empirically-driven realistic agents and parameters for studying other vulnerable populations in the agent-based modeling can utilize this framework. This is achieved thanks to the context independent structure of this framework.

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CHAPTER 1

INTRODUCTION

"Everyone has the right to a standard of living adequate for the health and well-being of himself and of his family, including food, clothing, housing and medical care and necessary social services, and the right to security in the event of unemployment, sickness, disability, widowhood, old age or other lack of livelihood in circumstances beyond his control."

Article 25.1 of Universal Declaration of Human Rights [1]

Seventy-two years after the United Nations' Declaration of Universal Human Rights, there remain millions of people around the world for whom this standard of living is not attainable, regardless of the development ranking of a country. Even in developed countries, many live below the poverty line. In 2019, there were 34 million people living in poverty in the United States, which is 10.5% of the population [2]. The World Bank [3] defines the poverty line as "the expenditure necessary to buy a minimum standard of nutrition and other basic necessities and a further amount that varies from country to country, reflecting the cost of participating in the everyday life of society." This definition implies that even low-income individuals living slightly above the poverty line do not enjoy a standard of living defined as a basic human right by the United Nations. This is due to a lack of financial resources to act as a protective cushion against "the events of unemployment, sickness, disability, widowhood, old age or other lack of livelihood in circumstances beyond their control" [1], which can abruptly shift people from precarious economic circumstances into poverty. Therefore, low-income level, whether below or slightly above the poverty line, is one of the major causes of vulnerability. While there are multiple definitions for different contexts, "vulnerable population groups" are primarily those who are economically disadvantaged, the uninsured, racial and ethnic minorities, the elderly, the homeless, and those with chronic health conditions, including serious mental illness [4]. Unfortunately, these disadvantaged sub-segments of the population are mutually inclusive, meaning that a specific group of the vulnerable population can be identified in other sub-segments.

Older adults have combined traits of vulnerable population groups. Their vulnerability is due to low income, gender, ethnicity, health conditions, and the combination of these factors [5]. While creating solutions to address all aspects of their vulnerability is a highly complex problem, enabling easier access to their basic needs through improved mobility is one way of alleviating their vulnerability. Transportation is the essential link that connects older adults to resources in order to maintain an adequate standard of living. However, due to the car-dependent infrastructure of the United States, many older adults who have ceased or reduced their driving activities because of declining health experience difficulty in accessing their essential needs, such as food, medicine, and healthcare [6].

However, mobility does more for older adults than just meeting basic physiological needs: it supports their mental health and wellbeing, as well. According to Maslow's hierarchy of needs [7], shown in Figure 1.1, a person must meet all of the needs in the lower four levels of the hierarchy (physiological, safety, belongingness and love, and esteem) to achieve his/her full potential: self-actualization.

Figure 1.1: Maslow's Hierarchy of Needs [8]

These five steps are not meant to be in rigid order, meaning that the satisfaction of needs is not an all-or-none phenomenon. For example, older adults' need for friendship and freedom may co-exist with their safety and physiological needs. However, an older adult who is experiencing hardship in accessing to healthcare and nutritious food will not have properly functioning body to enjoy friendships and family and to have freedom.

The most adverse impacts of lack of mobility occur in the first two steps of the hierarchy, such as limited access to healthy food and inability to access adequate healthcare services. The accumulated negative impacts of mobility deficiency disseminate to higher steps of the hierarchy and prevent older adults from experiencing love, esteem, and their full potential. Therefore, transportation is a significant component for vulnerable older adults to satisfy and sustain their physiological and safety needs [9] so that they can climb up the hierarchy.

This dissertation seeks to provide a greater understanding of the value of improving the mobility of urban older adults to allow them to access the resources they need, so that they are one step closer to having an adequate standard of living.

1.1 Transportation of Older Adults

It is estimated that one in five Americans will be 65 or older by 2030 [10]. In 2013, 48% of the elderly population (19.9 million) in the United States was economically disadvantaged due to low income levels, and those aged 80 and older had a greater economic disadvantage (58.1%) than individuals aged 65 to 79 (44.4%) [5]. Financial constraints, in addition to declining cognitive and physical health, are the primary reasons for the elderly to cease driving [11]. Driving cessation, whether due to low income or deteriorating health, creates a major challenge for elderly people living in car-dependent countries such as the United States. Non-driving elderly people have reported that their ability to meet their basic physiological needs – such as accessing food, medicine, and healthcare – are negatively impacted after driving cessation. While elderly people without financial constraints can afford to hire safe and secure transportation services, such as a taxi or ride-share, these options are difficult or impossible for low-income elderly to access. Furthermore, many older people report that they are not willing to use public transportation due to limited service availability, concerns of personal safety and security, and lack of comfort [6]. While the non-driving elderly identified riding with family or friends as the best option, they are reluctant to ask, due to the feeling of being a burden [6].

In Texas, the elderly population has increased by 43% from 2010 to 2019, from 2,601,886 to 3,734,229, respectively [12]. Dallas, Texas ranks 65th out of 100 U.S. cities in terms having the best public transportation. In addition, its public transit system receives one of the lowest scores for accessibility and convenience, and public transit resources [13]. Dallas-Fort Worth is the most definitive car-oriented metro area in the United States [14], lacking the solutions to meet transportation needs of the elderly.

Rideshare services provide an innovative potential solution to address the lack of public transportation. Uber[1] and Lyft[2] are commercial examples of utilizing drivers' free time and capacity in their cars to provide a flexible and comfortable transportation solution. However, older people do not prefer to use these services due to the concerns of safety and security [15]. In addition, the cost of these services is a limiting factor, especially, for low-income older adults. Fortunately, there are non-profit organizations to address the transportation needs of older people. ITNAmerica[3] and Drive a Senior[4] are volunteer-driven organizations, where volunteer drivers use their own cars and serve the transportation needs of the elderly, regardless of their income level, to enable access to basic shopping, healthcare, and recreational needs. Drive a Senior operates 5 branches in Austin, Texas, and the surrounding region. These branches provide free transportation with volunteer drivers for seniors aging in place. The motivation of Drive a Senior is to provide access to essential services and resources for older adults who do not have family members close-by, cannot use public transportation options due to physical limitations, need individual attention, and/or cannot afford taxi and rideshare services on a fixed income. However, there are currently no volunteer-driven transportation options to serve the older adults living in Dallas-Fort Worth. The potential of a volunteer-driven transportation service to address mobility needs of older adults in urban North Texas is therefore unknown.

Designing effective transportation solutions and senior-friendly improvements to existing transportation options requires a thorough understanding of heterogeneous older adult populations, since older adults are highly diverse with respect to demographic factors, health status, and their needs, perceptions, preferences, goals, and motivations. However, understanding older adults' heterogeneity and transportation needs is empirically challenging due to their declining cognitive and physical health, which limits data collection [16]. The inherent complexity of transportation context exacerbates this difficulty due to high number of stakeholders, heterogenous populations with diverse needs, goals, and roles, and strong interactions between these populations, stakeholders, and environment with complex transportation networks. [17]. Given these challenges, the concept of user personas, in which a vivid qualitative representation of older adults is generated from empirical data, can provide a user-model that unifies and

[1] https://www.uber.com/
[2] https://www.lyft.com/
[3] https://www.itnamerica.org
[4] https://driveasenior.org

focuses transportation system designers and decision-makers on older adults' transportation needs. In developing and deploying decision support tools to understand senior-friendly transportation improvements, older adult personas can empirically inform the characterization and parameterization of human agents in an agent-based model, which is a computational modeling method that can simulate the world from the viewpoints of heterogenous older adults in an artificial representation of real life [18], [19].

1.2 Research Questions and Contributions

I propose to find the answers to the following questions in this dissertation:

1. How can empirical human behavior data be used to define realistic agents to populate an agent-based model to study enhancements to older adults' mobility?
2. How can the concept of user personas be leveraged to unify transportation planners' focus on the transportation needs of older adults?
3. How can behavior functions for use in defining agent decision logic be derived from incomplete quantitative empirical behavior data?
4. How can agent-based modeling be used as a decision support tool to understand the impact of novel transportation solutions and senior friendly improvements to the existing transportation options on older adults in Dallas, Texas?

This research makes the following contributions to the literature:

- A systematic framework to translate survey data to realistic agents and empirically-driven behavior functions for use in agent-based modeling
- An approach to involve stakeholders and incorporate their expertise in agent development in order to establish their trust in the agent-based model built in support of their decisions
- The impact of implementing senior friendly improvements to existing transportation options on older adults' satisfaction levels with these options
- The value of community-tailored volunteer-driven crowd-sourced transportation that increases accessibility to essential resources for older adults in Dallas, Texas

1.3 Organization

Chapter 2 describes development of *personas* of the community-dwelling older adults living in car-oriented Dallas, Texas. Transportation survey data collected from community-dwelling older adults is used to develop the personas via a clustering methodology identifying the naturally-occurring groups of the older adults. The personas revealed the transportation needs and attitudes of the older adults while creating a unified and vivid understanding of the low-income elderly for transportation designers and providers. A *House of Quality* is used to determine the degree to which existing/proposed transportation services meet older adults' needs by utilizing the personas as the voice of the customer. Chapter 3 describes the process of role playing for personas by utilizing *Potentially All Pairwise Rankings of All Possible Alternatives (PAPRIKA)* methodology to derive personas' weights for the attributes of transportation modes, based on personas' own criteria for the different modes. The resulting weights and scores for each criterion are used to develop utility functions to understand older adults' satisfaction levels for different transportation modes. A conceptual agent-based model with the primary personas is developed to study personas' satisfaction levels for their transportation options. Chapter 4 concludes the dissertation and details the future work.

CHAPTER 2

A STAKEHOLDER-DRIVEN APPROACH TO UNDERSTANDING THE TRANSPORTATION NEEDS OF COMMUNITY-DWELLING OLDER ADULTS

2.1 Abstract

A structured stakeholder-driven approach is presented to identify transportation needs for community-dwelling older adults based on two system design tools: personas and the House of Quality (HOQ). Personas facilitate the incorporation of the motivations and needs of these older adults into transportation decisions with hypothetical users based on empirical data, thereby providing an objective representation of the most vulnerable community-dwelling older adults. The HOQ quantitatively maps the needs of community-dwelling older adults to existing transportation services and key characteristics of improved or new transportation services to prioritize solutions that satisfy the needs of older adults. Combining these approaches offers a holistic, systematic, and user-centered approach to addressing the mobility needs of both driver and non-driver community-dwelling older adults.

A case study on community-dwelling older adults located in Dallas, Texas, is used to demonstrate the development of personas using cluster analysis on data collected from a travel behavior survey. Three primary personas are identified as the voice of the most vulnerable non-driver community-dwelling older adults. The quantitative mapping of their needs to the transportation options available to them (public transit, paratransit, taxi, rideshare, and rides with family and friends) indicates that none of the existing options meets all of their mobility needs. The results suggest that implementing novel transportation solutions and changing existing transportation systems will be necessary to address the challenge of improving the mobility and quality of life of older adults in Dallas, with a focus on financial assistance, on-demand, trusted travel partners, and private and semi-private transportation options.

2.2 Introduction

For older adults, maintaining quality of life depends on having continuous mobility [11], not only to access resources to satisfy their basic needs, but also to have control over their lives, be independent, maintain their status, be included in society, and enjoy traveling [20]. Mobility also enables social connections and physical activity, which provide mental health benefits for older adults [21]. However, in the United States, mobility depends heavily on transportation via private vehicles, since the majority of U.S. cities lack sufficient, safe, and reliable public transportation options to meet individuals' travel needs [22]–[24]. For example, many cities offer paratransit services, but their limited schedules, destinations, and hours of operation discourage many older adults from using them [25]. As a result, even older adults living in major cities with public transportation tend to travel by private vehicles [26].

Furthermore, the first baby boomers, who turned 65 in 2011, were the first generation to grow up with cars. More than 75% of this generation is expected to age-in-place in their suburban and rural homes, where they have a familiar built environment and an established community setting [27], and most of these individuals will continue driving their personal cars [28]. However, these community-dwelling older adults will eventually cease driving, due to declining physical and cognitive health and/or insufficient disposable income to cover the expenses of owning and maintaining a car.

While non-driver community-dwelling older adults have some alternatives to public transportation, these often fail to meet their basic and emotional needs. The most preferred mode of transportation for non-driver older adults is riding with someone familiar with whom they can feel safe and have conversations during the rides [6]. Riding with adult children, neighbors, or someone else familiar from the community has been the backbone of senior transportation in the United States [29] and provides the desired personal connection. On the other hand, these older adults feel conflicted about asking for rides from their family and friends due to feelings of being a burden [6]. Rideshare services are another option that offer autonomy and spontaneity. However, older adults tend to be hesitant to use these services for their transportation needs, due to fear of riding with a stranger [30] and safety concerns over a lack of thorough car safety inspections [31]. Security of personal information is another concern for older adults, given recent data breaches at Uber [15]. Therefore, when community-dwelling older adults are no longer able to drive, they face a high risk of losing mobility, leading to social isolation and depression [32].

Designing transportation solutions and improving existing transit options to address mobility issues requires an understanding of the composition of a growing and heterogeneous older adult population. By 2030, the number of people aged 65 and older in the United States is projected to reach 71 million – approximately 20% of the population [33] – and they are becoming increasingly diverse [28]. Furthermore, the complexity of older adults' travel patterns and needs is increasing [34], due to multifaceted relationships among individual and socio-demographic characteristics, cognitive and physical health, transportation cost, information and service provisions, and different types of built environment [35]. These factors pose new challenges for the design of transportation solutions for older adults. In particular, understanding and accounting for heterogeneous personal and environmental characteristics is crucial in addressing their transportation needs [35]. However, this has received very little attention in the existing literature [36].

Designing transportation solutions that provide continuous mobility for older adults requires consensus among multiple diverse stakeholders, including government officials, policymakers, funding agencies, land use planners, and transportation providers, along with consistent user involvement. Therefore, a focused and unifying user model that provides an objective picture of actual transportation users and considers their goals, motivations, and behaviors is essential to ensure that the resulting transportation system's features meet the needs of its primary beneficiaries. However, in transportation and gerontology studies, data collected on older adults are typically presented as a disjoint array of artifacts (e.g., excerpts, graphs, figures, factual statements) that segment them into groups according to demographics, mode choices, and other travel activities. For example, Cevallos et al. [23] recommended that public transit agencies apply market segmentation as a way of addressing older adults' transportation needs, thereby narrowing service improvements to a smaller group of transit customers. While market segmentation provides a general understanding of different groups of older adults as the users of transportation solutions, this approach fails to incorporate their motivations, behaviors, and goals [37]. Furthermore, a lack of a unifying user model allows gaps in understanding to be filled with assumptions, which are subject to the biases of transportation designers, providers, and other decision-makers. According to Pruitt and Adlin [38], these assumptions may stem from personal experiences and cultural norms, and the biases may be unconscious, singular, and undisclosed. Design decisions that are based on such assumptions may result in suboptimal transportation systems that do not meet users' needs.

The aim of this study is to provide a structured stakeholder-driven approach to identifying transportation needs of community-dwelling older adults. This new approach is demonstrated using a case study on community-dwelling older adults in Dallas, Texas. Survey data was collected and then analyzed using cluster analysis, which identifies and characterizes naturally occurring groupings among the survey participants. These resulting clusters were used to develop personas to identify the needs of community-dwelling older adults, which were then mapped to the attributes of existing transportation services to determine the degree to which these services meet older adults' requirements. Figure 2.1 details the proposed approach.

The paper is structured as follows: Section 2.3 explains the concept of personas and reviews key factors impacting older adults' mobility and transportation behaviors. Section 2.4 describes the analysis methodology, detailing the data collection process, data preparation, cluster analysis, and persona development. In section 2.5, a mapping of the resulting personas' transportation requirements to the attributes of existing transportation services is performed using a House of Quality. In sections 2.6 and 2.7, results and implications are discussed, with a summary and plans for ongoing and future work concluding the paper.

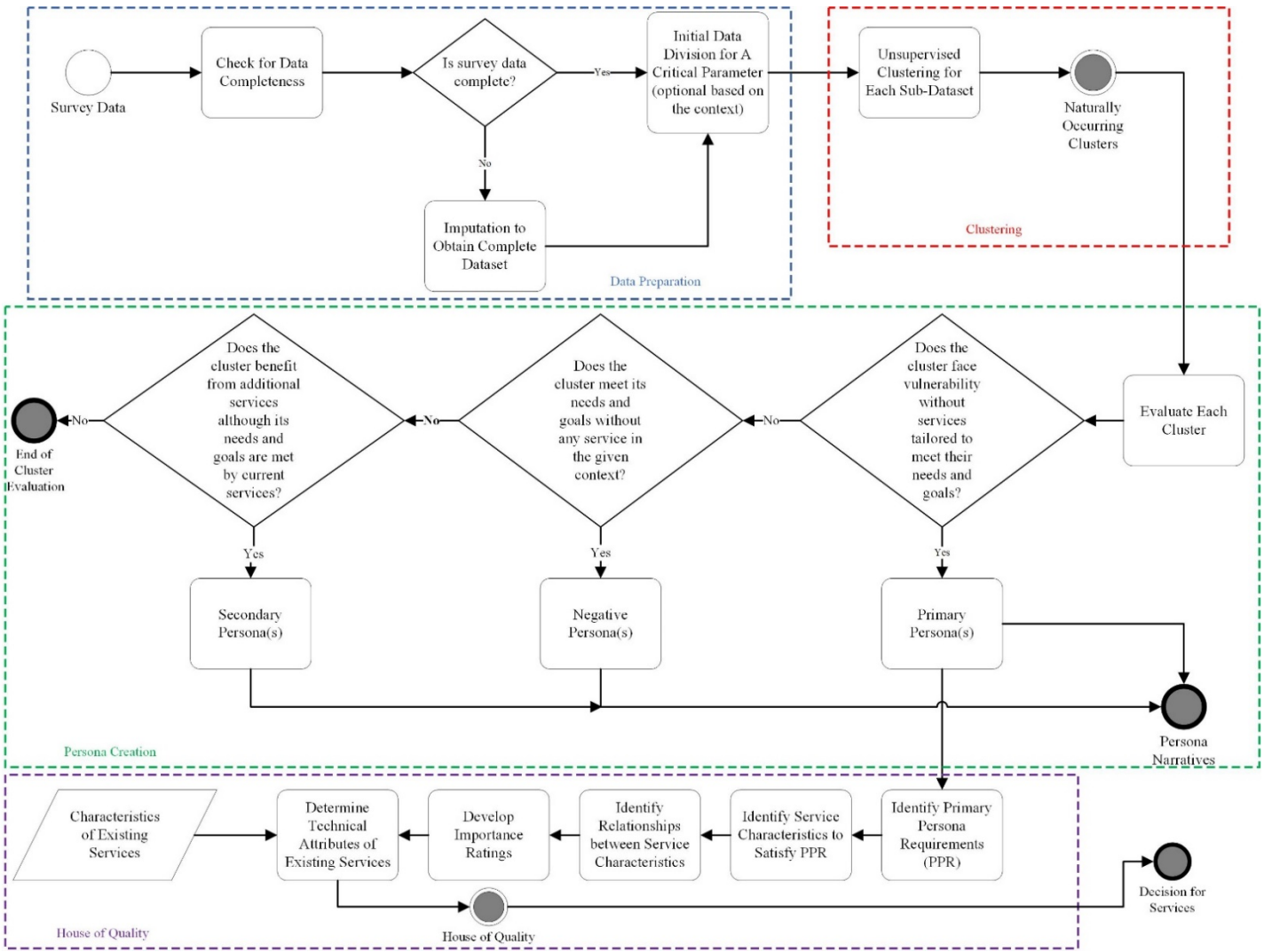


Figure 2.1: Structured stakeholder-driven approach to identifying transportation solutions for community-dwelling older adults

2.3 Background and Literature Review

2.3.1 Personas

The concept of personas originated in the field of interaction design as essential building blocks of software product development. In his seminal book *Inmates Are Running the Asylum*, Cooper [39] defines personas as "hypothetical archetypes of actual users". According to Pruitt and Adlin [38], personas are "fictitious, specific, concrete representations of target users". The role of personas is to address the need to represent users' personalities, perspectives, attributes, and goals [37]. In human-centered design, personas eliminate the "elastic user" phenomena, which is the tendency of designers to incorporate their own (often mistaken) perceptions of users into the product [39]. For this reason, personas support system design decisions in many different fields. For example, Sim and Brouse [40] integrated personas into requirements engineering for an improved understanding of user needs, behaviors, tasks, goals, and requirements in a web applications domain. Miaskiewicz and Kozar [41] conducted a Delphi study with a group of panelists who were experts in personas, which produced an extensive list of the benefits of using personas, including an emphasis on users, a prioritization of service and user requirements, the prevention of self-referential design, and greater empathy for users. Thus, using personas to address the mobility needs of community-dwelling older adults centers the focus on these individuals and their mobility goals, rather than the constraints emerging from transportation policies, budgets, providers, designers, and other stakeholders involved in decision-making. Personas can be used to prioritize the most vulnerable older adults, whose mobility needs require immediate attention to make their basic needs easily accessible and improve social aspects of their lives. In addition, personas can help to determine exact mobility problems of older adults and define the scope of these problems. Furthermore, the use of personas allows established organizational assumptions about older adults' mobility to be challenged. By creating a shared knowledge of older adults, personas can provide intuitive understanding and improved communication among stakeholders while creating awareness of how older adults' mobility needs are different from stakeholders' self-perceived understanding of those needs. Moreover, personas can help to create emotional identification with older adults, which can unify decision makers in addressing their mobility needs. These benefits emerge from the underlying strength of personas in organizing and presenting raw research data of a diverse population in a way that is the most natural to the human mind.

Reeder et. al. [42] utilized personas to gain insights into the capabilities of members of the oldest old age group as Information Technology (IT) users. The study produced a set of design recommendations addressing the needs and obstacles of older adults while accessing care services via IT. Wöckl et al. [43] created personas representing 12,500 senior adults aged 60 and older from northern, central, and southern regions of Europe in order to create a common understanding of these senior citizen among developers of Information and Communications Technology (ICT) solutions for older adults. The tool developed in this study is a "personas filter" which provides 30 basic personas representing European senior citizens, while allowing developers the capability of customizing according to the needs of persona users. This layered persona approach eliminates persona creation from scratch for each different ICT solution for older adults.

2.3.2 Factors Impacting Older Adults' Mobility, Transportation Behaviors, and Needs

The population of older adults in the United States is more heterogeneous than ever, resulting in diverse mobility and transportation needs. Therefore, one of the main goals of using personas in this study is to identify the most vital factors affecting the mobility needs of the most vulnerable older adults from a diverse population. According to the gerontology and transportation literature, the most frequently studied demographic factors impacting older adults' mobility include age, health, gender, education, income, race, and ethnicity.

2.3.2.1 Age and Health

While age is not the sole predictor of older adults' transportation mode choices [44], their preferences evolve and change as they step into older age cohorts. In particular, older adults reduce their driving activities incrementally until driving cessation [27], [45]. Younger older adults, aged 65 to 75, are not significantly different from adults aged 18 to 59 in terms car usage, and they travel longer distances by car after entering retirement [34]. By contrast, Rosenbloom [27] indicates that 80% of those aged 85 and over only drive for half of their trips and avoid driving at night, during hazardous weather conditions, and at rush hour. Compared to previous generations, older adults of today are expected to experience longer durations of relative wellness while coping with multiple chronic diseases [46]. However, it is inevitable that older adults will experience a decline in physical and cognitive health with increasing age, and vision impairment and slowed reaction time will eventually lead to driving cessation [47].

However, the health of older adults in the same age cohorts differs greatly [48], and their transportation preferences and decisions depend on their self-perceived health, rather than their chronological age.

In general, as older adults age, they tend to avoid using public transportation [49]. The trouble of walking to a bus stop outweighs the difficulties of driving a car [27], [36]. Other health-related reasons to avoid public transportation include the inability to maintain balance during rapid acceleration and deceleration and issues with getting on and off the vehicle [6]. As a result, many older adults persist with driving until they are no longer able to operate a car safely. According to Adler and Rottunda [47], older people cease driving by self-acknowledging the hazardous impacts of driving with their declining health, or they are influenced by their family and friends to give up driving. At that point, they may consider using special transportation services, such as paratransit and senior vans, to meet their transportation needs [44].

2.3.2.2 Gender

Research has determined that older women have less mobility than men [11], [36], [45], [50], primarily because they outlive their male counterparts. As women live longer, their disability rate increases [34], which creates a greater need for transportation assistance. However, older women are reluctant to utilize public transportation and walking after giving up driving [11], and women aged 65 and older are twice as likely to live alone, due to being widowed and not having children nearby to live with them [51].

Older men are less likely than older women to voluntarily cease driving [36]. Older women tend to self-regulate and reduce their driving activities [52], and they also cease driving sooner than men [53]. However, according to Edwards et. al. [54], the rates of driving cessation among modern cohorts of older women are declining, with women managing most of the household activities outside the home that require travel [46]. In addition, 70% of women work either part-time or full-time and therefore engage in more driving, thanks to higher professional engagement, income, and education [52].

2.3.2.3 Education and Income

Transportation mobility of older adults is positively correlated with their education levels [50]. However, while the general assumption is that income level is strongly associated with education level, Kim [50] also determined that

income is not significantly associated with the mobility of older adults. Coughlin [46] explains this contradiction: older adults with more education are engaged in community and volunteering activities, visit family and friends, and go to libraries for their self-development. Therefore, advanced levels of education are associated with larger social networks [55], which encourage older adults to undertake additional trips, rather than traveling only for basic needs. In a later study, Kim [11] indicated that the household income of the elderly is often related to education levels. Regardless of the relationship between education and income levels, many studies show that low income leads to mobility deficiency [49], [51], [56], [57].

Older adults with incomes of $35,000 or higher prefer to drive their personal cars, or they will utilize carpools and vanpools if their health condition limits their driving abilities [48] – public transportation is their least-preferred option. By contrast, older adults with incomes of $20,000 or less are less likely to drive a car [49], because they cannot afford the cost of owning, maintaining, and operating a car even if they are still able to drive [58]. Regardless, most non-driving older adults are likely to be among the oldest old, living alone and having less than 14 years of education [59]. Women are more likely to live in poverty and therefore lack transportation options that enable them to have access to the services and goods they need [51]. Compared to men, older women have relatively more financial vulnerability, with limited disposable income after retirement. Hence, this income inequality creates a transportation gender discrepancy [56].

2.3.2.4 Race and Ethnicity

Race and ethnicity have an important impact on the mobility of older adults and their transportation activities and preferences. White older adults make longer and more frequent trips than older adults from other racial and ethnic backgrounds [27]. In the case of driving cessation, white older adults favor getting a ride with a friend or family member over using public transportation or walking [44], while Asian-American and Black older adults are likely to choose public transportation more often than older Whites [49]. Freund and Szinovacz [53] found that Black and Hispanic older adults are more likely to avoid driving a car and prefer to limit their driving to short distances. In addition, older Black adults lean towards using paratransit and senior vans, and Hispanics are more likely to use public transportation when they can no longer drive [44].

There is a significant mobility difference between men and women across racial and ethnic groups [27]. Older Black men travel 32 percent less than older White men, and older White women make trips three times more frequently than older Black women [50]. This discrepancy is observed across all income levels. Furthermore, older Hispanic women with less than $20,000 in annual household income are 50% less likely to make daily trips than older Black women [49].

2.4 Methodology

This section describes the travel behavior data collection process and results, the cluster analysis and resulting naturally occurring groups of older adults, the persona development process and the identification of the most vulnerable older adults, the creation of the House of Quality and the ranking of mobility and transportation improvements, and the assessment of available transportation options against the needs of the personas.

2.4.1 Data Collection: Travel Behavior Survey

A travel behavior survey with 167 community-dwelling older adults aged 55 and older in Dallas, Texas, was conducted to identify their demographics, health and well-being, mobility needs, transportation behaviors and options, mobility, and transportation barriers, and expected future improvements from public or private transportation entities. These survey metrics were identified from the literature [60]–[62]. The AARP Community Survey Questionnaire template [63] was implemented to capture the eight domains of age-friendly communities identified by World Health Organization: the built environment, transport, housing, social participation, respect and social inclusion, civic participation and employment, communication, and community support and health services [64].

The survey data was collected in four sessions. The first two sessions took place during volunteer training sessions at the Senior Source[5] in Dallas on February 18, 2020, and March 12, 2020. In the first session, a high proportion of survey questions were not answered by the participants. After receiving feedback from Senior Source staff and conducting a thorough analysis of the responses, the primary reason for poor response turnover was identified as the length and difficulty of the survey. The survey structure and terminology were simplified without

[5] The Senior Source in Dallas, TX serves older adults with volunteer opportunities, nursing home resources, guardianship services, financial assistance and protection, fraud and scam prevention, employment services, and support for caregivers [111].

any changes in the collected metrics, and the new version was used for the second, third, and fourth sessions. Due to the COVID-19 outbreak, the third and fourth sessions, totaling 76 older adults, were conducted via phone surveys from mid-March until June 2020 via multiple sessions. All participants received a $5 gift card as an incentive. This study was approved by the University of Texas at Arlington Institutional Review Board (#2020-0034).

Most (40%) of survey participants were 65 to 75 years old, while the second largest group (32%) were aged 75 to 85. Female participants comprised 84% of respondents. A significant proportion (34%) of participants reported having less than $10,000 in annual income, and 38% have at most a high school diploma. Retired older adults made up 70% of the total survey participants, and 68% live alone. The majority of participants are Black or African American, followed by White or Caucasian, Asian, and Hispanic or Latino at 62%, 20%, 6% and 2.4%, respectively. Seventy-seven percent of the participants rated their overall physical and mental health as good or beyond good, and 57% reported that they can walk more than 0.25 miles.

For 47% of the participants, driving is their primary mode of transportation, followed by 14% using public transportation, 13% having others drive, and 13% walking or biking. While driver participants make six trips per week on average, the participants using public transportation, driving with others, and walking or biking take trips only three, one, and two times per week, respectively. The majority of non-driver participants (43%) use public transportation while 17% ride with paratransit. The least-used modes among the non-driver participants are ride-hailing services and taxi/cab (4% each). Walking or biking is perceived as the least safe mode for driver participants, while non-driver participants included ride-hailing services and taxi/cab as the least safe modes of transportation. Anecdotally, the survey participants are not comfortable using ride hailing and taxi/cab due the fear of riding with strangers. For non-driver participants, cost is a significant factor for all modes except walking or biking, while the driver participants find a taxi/cab expensive. Both non-driver and driver participants find the availability of public transportation and paratransit insufficient (e.g., infrequent schedule and limited operation hours). Driver participants report that they lack knowledge about ride-hailing and paratransit services. On the contrary, non-driver participants indicated that they are familiar with ride-hailing and taxi/cab services.

The survey participants considered public transportation and paratransit services to be crucial for their independence when they can no longer drive themselves. Safe and accessible streets and audio/visual-aided intersections to enhance walkability were also indicated to be important to maintain independent living. On the other

hand, ride-hailing and taxi/cab were deemed less important for living independently since the majority of the participants are not comfortable using these services.

Social networks and frequently visited places are the primary sources of transportation information for the survey participants. While 36% of the participants sought transportation information from family members, friends, neighbors, and doctor offices, 32% used local aging facilities, faith-based organizations, and AARP to access information. When asked about their frequency of Internet use, 57% of the participants reported that they never used the Internet to access transportation information due to experiencing difficulties in accessing the Internet or using smartphones and computers. Only 3% of the respondents used the Internet several times a day.

In addition to nonresponses that occurred due to the length and difficulty of the survey, some item nonresponses were observed for questions in which the participants did not wish to reveal sensitive demographic factors, such as age, income, and marital status, or they had never used some of the presented transportation options and therefore did not have adequate knowledge. A total of 1,322 values were missing out of 21,209, (a 6.23% missingness rate). To avoid nonresponse bias and information loss, missing data was imputed. Because the data exhibited non-monotone arbitrary and missing at random (MAR) patterns, the Monte Carlo Markov Chain (MCMC) method was used to impute all missing values [65], yielding a complete data set. SAS 9.4 was used to perform MCMC imputation.

2.4.2 Cluster Analysis

Cluster analysis was performed on the imputed travel behavior survey data to identify naturally occurring groups of the community-dwelling older adults, in which the older adults in the same range of demographic factors with similar transportation needs and behaviors are grouped together. While naturally occurring groups of survey participants can be identified without using advanced statistical tools in small datasets, this task is daunting in large datasets, such as the travel behavior survey described in the previous section. There are several methods for cluster analysis, and the selection of which method to use depends on the characteristics of the collected data and the individual methods. The number and types of input variables, the desired output metrics and features, and requirements on having a pre-determined number of clusters are factors to consider before selecting the appropriate clustering method.

Prior to finalizing the clustering method, several sessions of cluster analysis were tested with candidate methods in order to select the most suitable method in identifying the naturally occurring groups from the travel behavior survey data. One caveat found in these test runs was the effect of gender on interpretation of the resulting clusters due to non-homogeneity within this factor. To eliminate future confusion in interpretation, the entries for female and male participants were manually separated into two initial clusters prior to applying cluster analysis.

Next, the male and female groups were exclusively divided into clusters by applying Ward's method of hierarchical clustering with Euclidean distances [66] on age, status of current car possession, education level, marital status, and ethnicity. The parameters for cluster analysis are based on the factors impacting older adults' mobility, transportation behaviors, and needs. Although older adults rated their health status based on their self-perception regardless of their age, health status was not used as a clustering factor due to the high correlation between increasing age and declining health status. Furthermore, income level was left out of the clustering since it was highly correlated with education level. By contrast, marital status and ethnicity had weak correlations between each other and with the rest of the clustering factors; therefore, both were included in the cluster analysis. It was decided that the number of naturally occurring groups would not be restricted to a predetermined number of clusters, to avoid introducing bias to the resulting clusters. Minitab Data Analysis was used to perform the cluster analysis, yielding 13 female and 4 male clusters, as shown in Table 2.1. The clusters served as the basis for persona development.

Table 2.1: The results of cluster analysis

Cluster	Gender	Age	Car	Education Level	Marital Status	Ethnicity
1	Female	75	No	High School or Equivalent	Separated or Divorced	Black or African American
2	Female	91	No	Post-high school education/training	Widowed	White or Caucasian
3	Female	63	No	4-year collage degree	Single - Never married	White or Caucasian
4	Female	62	No	High School or Equivalent	Single - Never married	Black or African American
5	Female	77	No	High School or Equivalent	Married or Living with a partner	Asian
6	Female	73	Yes	Post-high school education/training	Married or Living with a partner	Black or African American
7	Female	71	Yes	Graduate or professional degrees	Married or Living with a partner	White or Caucasian
8	Female	67	Yes	Post-high school education/training	Separated or Divorced	Other: Hispanic
9	Female	69	Yes	2-year collage degree	Widowed	Black or African American
10	Female	67	Yes	High School or Equivalent	Separated or Divorced	Black or African American
11	Female	78	Yes	K-12 grade	Widowed	Black or African American
12	Female	68	Yes	Graduate or professional degrees	Separated or Divorced	Black or African American
13	Female	81	Yes	2-year collage degree	Widowed	Black or African American
14	Male	78	No	High School or Equivalent	Married or Living with a partner	Asian
15	Male	70	Yes	2-year collage degree	Separated or Divorced	Black or African American
16	Male	65	Yes	4-year collage degree	Married or Living with a partner	White or Caucasian
17	Male	73	No	2-year collage degree	Single - Never married	White or Caucasian

2.4.3 Persona Development for the Community-dwelling Older Adults

First, the primary, secondary, and negative persona(s) must be identified. The primary persona(s) is the cluster whose needs and goals cannot be met with a service designed for any other persona [39]. The secondary persona shares some attributes with the primary persona(s), as well as additional specific needs that do not require immediate action and can be satisfied with the services designed for the primary persona [37]. The negative persona (or anti-persona) is a reminder to all stakeholders for whom they should not design the service. Unlike the primary and secondary personas, the negative persona communicates what is not the target of a service [37].

The primary persona(s) representing older adults will be the most vulnerable in terms of mobility. Clusters 1, 2, and 3 did not own a car, nor they could afford a car. Their health and financial status were limiting factors to use existing transportation options and live independently. In addition, they reported missing trips for basic needs and leisure activities. Cluster 4 did not own a car, but they reported that their main transportation mode and source of mobility was riding with others. Clusters 6 through 13, 15, and 16 owned a car that they can afford to maintain and keep in their possession. While these clusters may experience some difficulties with driving due to aging, they are still able to drive everywhere. Clusters 5 and 14 represent older adults who are married and reside in the same household. While both were above 75 years and had low income, they reported their health as excellent compared to other older adults and were able to meet all their needs by using public transportation and walking. Cluster 17 owns a car and considers driving as the only option for transportation without any interest or knowledge of other transit options.

Based on this analysis, clusters 1, 2, and 3 are the most vulnerable, with insufficient transportation options to maintain an independent life without disruptions in their day-to-day activities. Therefore, these clusters are the primary personas. Clusters 4 through 16 can satisfy their transportation needs with their current arrangements. However, they are aware of the challenges ahead as they age and decline in health. These clusters can benefit from the solutions targeted to the primary personas. Therefore, clusters 4 through 16 make up the secondary personas. Cluster 17 is the negative persona who should not be targeted for designing transportation services for older adults in Dallas, Texas. The primary personas are described in detail in Table 2.2, Table 2.3, and Table 2.4. The secondary personas and the negative persona can be found in Appendix A to Appendix N.

Table 2.2: Primary persona - Beatrice

<table>
<tr><td>BEATRICE
  Age:91
White American</td><td> 
Home Income Social Connections Transportation
Health: Mobility: Transportation Options:</td></tr>
<tr><td colspan="2"><u>About</u>
Beatrice has a high school degree and training in a trade school. Beatrice lives alone in a house she owns located 16 miles north of Downtown Dallas. Beatrice’s annual income is $43,000.</td></tr>
<tr><td><u>Health Background</u>
As a stay-at-home mother, she was careful with her and her family’s diet. She was always physically active inside and outside of the house.</td><td><u>Health Status</u>
• Expected deterioration due to aging
• Able to walk 0.25 miles in 20 minutes
• Self-perceived physical health rating is good</td></tr>
<tr><td><u>Social Connections</u>
Beatrice talks to her children everyday who live out-of-state. Beatrice likes spending time by herself with gardening, crochet, and word puzzles.</td><td><u>Social Status</u>
• Rarely feels lonely and socially isolated</td></tr>
<tr><td><u>Transportation Options</u>
Beatrice gave up driving willingly at the age of 85. She uses special transportation for grocery trips and public transportation to go to doctor appointments and bank. She would like to use ride hailing services, but she is concerned about riding with strangers and the cost.</td><td><u>Mobility Status</u>
• Rarely misses grocery store trip or doctor appointments
• Difficulty in reaching to bus stops in Texas summers
• Using public transit and walking between stops and locations while carrying bags gets harder
• Unable to stay in balance while in transit
• May depend on other drivers for basic needs
• Feels pain when jostled by others, rapid accelerations, and decelerations.</td></tr>
<tr><td><u>Transportation Information</u>
Beatrice schedules her trips on her laptop once in every few weeks.</td><td><u>Accessing Transportation Information</u>
• DART’s website and printed schedules</td></tr>
<tr><td colspan="2"><u>Goals and Motivation</u>
Beatrice wants to live without being burden on other people. However, she sometimes wishes to have help from people she trusts who understand her needs. While Beatrice likes spending time in her home, she sometimes would like to visit her friends, but her transportation options limit her reach to her friends’ houses. Beatrice misses going to stores or recreational center whenever she wants.</td></tr>
<tr><td colspan="2">Satisfied: Not Satisfied: Disappointed:</td></tr>
</table>

Table 2.3: Primary persona - Cassandra

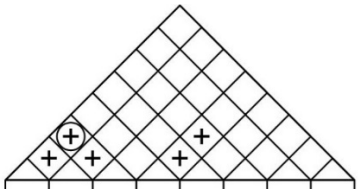
<table>
<tr><td>CASSANDRA
  Age:75
Black American</td><td> 
Home Income Social Connections Transportation
Health: Mobility: Transportation Options:</td></tr>
<tr><td colspan="2"><u>About</u>
Cassandra has a high school degree. She worked in retail industry since high school. Cassandra lives alone in a house she owns located 10 miles south of Downtown Dallas. Cassandra’s annual income is $14,000.</td></tr>
<tr><td><u>Health Background</u>
Cassandra had an unhealthy lifestyle due to her work and being a single mother. She did not have time to exercise and take care of herself. She reached for fast food as an easy meal option.</td><td><u>Health Status</u>
• Type-2 diabetes
• Vision impairment
• Able to walk 0.25 miles in 10 minutes
• Self-perceived physical health rating is good</td></tr>
<tr><td><u>Social Connections</u>
Cassandra does not like to depend on other people. Her closest child visits her every three weeks to help with her needs. While she has some friends and neighbors she reaches out, she lacks strong connections.</td><td><u>Social Status</u>
• Occasionally feels lonely and socially isolated</td></tr>
<tr><td><u>Transportation Options</u>
Cassandra uses public and special transportation for her monthly doctor appointment, visiting her friends and volunteering. She mostly depends on her daughter and neighbor for grocery shopping. Otherwise, her travel time increases by three times due to transfers between vehicles, long riding time in current routes, or waiting for others on special transportation.</td><td><u>Mobility Status</u>
• Occasionally misses grocery trip, doctor appointment, or a volunteering session
• Afraid of young delinquents on streets and in transit, especially at nights
• May depend on other drivers for basic needs</td></tr>
<tr><td><u>Transportation Information</u>
Cassandra reads AARP bulletin and bi-monthly magazine, and news on local newspaper for transportation information.</td><td><u>Accessing Transportation Information</u>
• Mail-in printed schedules and routes from DART
• Printed schedules from the Internet with others’ help
• Phonebook to call for information
• Friends and family</td></tr>
<tr><td colspan="2"><u>Goals and Motivation</u>
Cassandra wishes to have easier access to her basic needs. She wants to avoid falling down due to uneven sidewalks and sit down and rest during her walks. Cassandra wishes to participate in more voluntary activities and increase her social connections. She wants to be more aware of her transportation options and take additional entertainment trips at around midday and evenings without depleting her budget.</td></tr>
<tr><td colspan="2">Satisfied: Not Satisfied: Disappointed:</td></tr>
</table>

Table 2.4: Primary persona - Elizabeth

<table>
<tr><td>ELIZABETH
  Age:63
White American</td><td> 
Home Income Social Connections Transportation
Health: Mobility: Transportation Options:</td></tr>
<tr><td colspan="2"><u>About</u>
Elizabeth has 4-year college degree, and she worked as teacher for 30 years. Elizabeth lives alone in a rental apartment located 5 miles northeast of Downtown Dallas. Elizabeth’s annual income is $16,000.</td></tr>
<tr><td><u>Health Background</u>
Elizabeth had a major traffic accident 10 years ago and was hospitalized for 3 months. After the accident, she did not fully recover physically and financially, and she had to stop teaching.</td><td><u>Health Status</u>
• Deterioration due to aging and the accident
• Able to walk less than 0.25 miles at once
• Self-perceived physical health rating is fair</td></tr>
<tr><td><u>Social Connections</u>
Elizabeth has some friends who regularly visits her. She likes to keep herself occupied with reading and researching. Elizabeth feels fulfilled with volunteering activities. She likes to go to recreational centers and parks with her friends.</td><td><u>Social Status</u>
• Rarely feels lonely and socially isolated
• Feels depressed when not able to go outdoors</td></tr>
<tr><td><u>Transportation Options</u>
Elizabeth stopped driving due to her health and limited finances. She accesses her basic needs and attends her social activities by combining different modes of transportation.</td><td><u>Mobility Status</u>
• Rarely misses grocery store trip or doctor appointments
• May depend on other drivers for leisure activities</td></tr>
<tr><td><u>Transportation Information</u>
Elizabeth goes online at least once a day to check updates on time schedules, routes, and pricing.</td><td><u>Accessing Transportation Information</u>
• DART’s website and printed schedules
• Ride hailing apps</td></tr>
<tr><td colspan="2"><u>Goals and Motivation</u>
Elizabeth does not want to feel trapped. She wishes to go out whenever she wants for any reason without worrying for her well-being. Although she uses rideshare services, she cannot afford it frequently. She does not want to be limited by the changing transit schedules and routes. She prefers to have a direct transit to her destination to reduce her travel times and avoid the hassle of combining modes. Elizabeth wishes to have basic amenities close to her house.</td></tr>
<tr><td colspan="2">Satisfied: Not Satisfied: Disappointed:</td></tr>
</table>

2.4.4 House of Quality for Primary Personas

To determine the degree to which existing/proposed transportation services meet older adults' needs, the qualitative descriptions of the primary personas' transportation needs must be converted into quantitative measures. One tool that can be used for this purpose is the House of Quality (HOQ), which connects the voice of the customer (the customer requirements) to the voice of the development team of a specific product or service by creating a mathematically simple and user-friendly approach [67], [68]. Figure 2.2 shows the HOQ developed for this study.



Primary Persona Needs	Relative Importance Ratings	On-demand Service	24/7 Service	Financial Assistance	Private and semi-private Transit	Trained Operators	Trusted Travel Partnes	Senior Friendly Street Infrastructure	Increased Route Coverage and Service Frequency	Dart Bus/Train	Paratransit	Taxi	Rideshare	Family & Friends
Affordability	8.3	9	9	9	9					4	4	1	1	5
Safety	9				3	3	3	9		0	4	3	3	5
Reliability	5.7		9				3		9	2	3	4	4	4
Availability/Accessibility	7.7	3	9	1					9	2	2	4	4	3
Assistance	3.7					3	9			1	3	2	2	5
Comfort	6.3				9	3		1		1	3	4	4	5
Walkability	9							9		1	3	5	5	5
Direct and Short Trips	6.3				3				9	1	2	5	5	5
Flexibility	5.7	3							3	1	1	5	5	4
Spontaneity	5.7	9	3							1	1	5	5	3
Scores		166	212	82	177	57	77	168	194					
Ranks		5	1	6	3	8	7	4	2					

Figure 2.2: House of Quality for older adult transportation

The first step in developing the HOQ is identifying customer/user needs. In an HOQ analysis, the customers' needs should be described in their own words [69]. The descriptions of the primary personas provided in Table 2.2, Table 2.3, and Table 2.4 depict the transportation needs of the most vulnerable older adults in Dallas, Texas. These needs, from the point of view of each persona, are summarized Table 2.5 and are categorized under umbrella words. Each need is then inserted into the leftmost column of the HOQ in Figure 2.2. While independence is the ultimate transportation need of older adults, it is strongly correlated to all of their other needs. Therefore, independence is not included in further analysis.

Table 2.5: The Transportation needs of the primary personas in their own words

The Transportation Needs of the Primary Personas	Umbrella Words
• Beatrice and Cassandra do not want to be dependent and burden on anyone • Elizabeth does not want to feel trapped	Independence
• Beatrice has hard time to walk to bus stops in Texas summers • Cassandra would like even sidewalks with places to sit down and rest during her walks • Elizabeth wishes to have basic amenities close to her house	Walkability
• Beatrice is concerned about riding with strangers • Cassandra is afraid of young delinquents on streets and in transit • Elizabeth does not want to worry about her well-being	Safety
• Beatrice misses going to stores or recreational center whenever she wants • Elizabeth wants to go out on a whim	Spontaneity
• Beatrice cannot carry her bags while waking and in transit	Assistance
• Beatrice is unable to stay in balance while in transit • Beatrice feels pain when jostled	Comfort
• Beatrice would like to visit her friends living far from public transit routes	Flexibility
• Elizabeth does not want to depend on the changing schedules and routes	Reliability
• Cassandra would like to be more socially active at different times of the day • Elizabeth wants to avoid the hassle of combining modes	Availability/Accessibility
• Beatrice would like to use rideshare if it was not costly • Cassandra believes that her transportation budget limits her • Elizabeth cannot afford rideshare although she wants to use it	Affordability
• Cassandra's travel time to basic needs increases by three times if she does not have anyone to give a direct ride • Elizabeth wishes to have direct transit to her destinations to reduce her travel times	Direct and Shorter Trips

After identifying the transportation needs of each persona, the needs are assigned importance ratings (shown in Table 2.6) based on a 5-level qualitative rating system with corresponding quantitative values: 1-very low, 3-low, 5-moderate, 7 high, 9-very high [70]. These ratings are derived from each persona's needs, goals, and motivations and are then averaged across all three personas to provide a relative importance for each need. The relative importance ratings are inserted into the second column of the HOQ.

Table 2.6: Importance ratings of primary persona needs

	Importance Ratings						
Needs	**Beatrice**		**Cassandra**		**Elizabeth**		**Relative Importance Ratings**
Affordability	High	7	Very high	9	Very high	9	8.3
Safety	Very high	9	Very high	9	Very high	9	9
Reliability	Moderate	5	Moderate	5	High	7	5.7
Availability/Accessibility	Moderate	5	Very high	9	Very high	9	7.7
Assistance	Very high	9	Very low	1	Very low	1	3.7
Comfort	Very high	9	Moderate	5	Moderate	5	6.3
Walkability	Very high	9	Very high	9	Very high	9	9
Direct and Short Trips	Moderate	5	High	7	High	7	6.3
Flexibility	Moderate	5	Moderate	5	High	7	5.7
Spontaneity	High	7	Low	3	High	7	5.7

In the second step of the HOQ analysis, common characteristics of transportation solutions are identified. These characteristics, which were derived from multiple reports and studies on transportation services for older adults, include: on-demand service, 24/7 service, financial assistance, private and semi-private transportation, trained operators, trusted travel partners, senior friendly street infrastructure, route coverage, and frequent service [23], [28], [29], [46], [71]–[73]. These eight characteristics are labels on the central matrix of the HOQ, which defines the strength of relationships between the transportation needs of the primary personas and the service characteristics using a 3-level scale: weak (1 in a triangle), medium (3 in a circle), and strong (9 in a donut) [67]. At the bottom of the HOQ, final scores of the service characteristics are achieved by vertically summing the multiplication of the relative importance ratings by each service assessment rating, yielding a priority ranking for the service characteristics. According to the HOQ rankings, 24/7 service has the highest priority, followed by increased route coverage and service frequency as the second, and private and semi-private transit (i.e., cars and vans operated by for-profit and non-profit organizations) as the third, reflecting the top preferences of the most vulnerable community-dwelling older adults in Dallas, Texas. However, the characteristics with low scores should not be disregarded based on their rankings since there may be correlations between the low- and high-ranking characteristics.

The “roof” of the HOQ contains the correlations between service characteristics. A strong correlation is indicated by a + sign in a circle, a positive correlation with a + sign, a negative correlation with a – sign, and a strong negative correlation with a – sign in a circle [67]. The roof of the HOQ suggests that positively correlated service characteristics should be implemented jointly. There is a positive correlation between on-demand service and 24/7 service since the premise of on-demand is access at any time. Use of on-demand services are strongly

correlated with financial assistance, since they are typically expensive [74], and the primary personas cannot afford expensive transportation services without assistance. Similarly, the positive correlation between financial assistance and 24/7 service indicates that traveling during late evening or early morning hours is limited by a lack of affordable transportation options. Private and semi-private transit operations are dependent on and therefore positively correlated with the trained operators and the assistance of the travel partners.

The final step of the HOQ analysis is the assessment of existing transportation options against the voice of the personas. The columns of the rightmost matrix of the HOQ are labeled with five transportation services that are available in the city of Dallas for older adults: DART bus/train, paratransit, taxi, rideshare, and family/friends. The values entered in this matrix show the performance of the service with respect to the persona needs (where 1 indicates poor and 5 indicates excellent). Based on the primary persona characteristics, bus, train, paratransit, and riding with family/friends are the most affordable transportation options. However, bus and train receive poor or fair scores on the remaining persona needs. While taxi and rideshare are rated at or above very good, fear of riding with a stranger, lack of financial assistance, and the cost of these services are limiting factors for older adults. In addition, riding with family and friends has limitations in regard to the availability of these trusted persons.

2.5 Discussion

This study describes and demonstrates a structured stakeholder-driven approach to identifying transportation needs of community-dwelling older adults. Data from a travel behavior survey conducted with community-dwelling older adults in Dallas, Texas, was used to develop personas, or representations, of these older adults, and a House of Quality was used to translate qualitative descriptions of these personas' transportation needs into a quantitative assessment of available transportation options.

The three primary personas represent the most vulnerable older adults in terms of transportation and mobility needs. All of the primary personas are female and are living alone on low incomes. This result reflects the literature, which states that female older adults experience a greater decline in mobility compared to their male counterparts. Their ages (63, 75, and 91) span the low, middle, and high sub-categories of the old age spectrum. This suggests that their poor health status, irrespective of age, is a primary limiting factor on their mobility. However, the primary personas expect to live independently, with safe and affordable transportation options that accommodate their need for comfort and assistance. They would like to go their destinations directly with the shortest travel times

possible, whenever they want. In addition, they would like to live in a crime-free environment that provides safe sidewalks, covered benches for resting at bus stops, and visual and audio aids at intersections. The primary personas emphasize the fact that older adults would like to continue living independently and taking trips for their well-being while traveling in comfort and feeling safe – like everyone else.

The results of the HOQ analysis indicate that public transit options in the city of Dallas meet the affordability requirements of the primary personas but perform poorly with respect to the remaining persona needs. Dallas Rapid Area Transit (DART) is the main public transit provider in Dallas, and its services include busses, light rail, and commuter rail. DART rail operates from 5 a.m. to midnight daily at every 7½-15 minutes during rush hours, and 20 minutes during the midday and weekends, and 30 minutes late at night. While DART's rail system stretches to distant suburbia, its park-and-ride stations mainly serve commuters trying to reach to city center at high speeds [75]. It is common to observe full parking lots at DART stations where working people living in suburban areas drive to stations and use DART rail system to complete their commutes. In addition, DART rail system is a north to south oriented rail system that does not reach vast swaths of Dallas. Operation hours of busses vary by neighborhoods and during holidays [76] but generally offer limited fixed-route service and infrequent service during midday when older adults travel the most. While DART provides paratransit service for older adults (the primary personas), it is limited to Monday-Friday from 8 a.m. to 5 p.m. [76], necessitating other transportation options for any trip taking place after 5 p.m. on weekdays or weekends. Given that 24/7 service and increased route coverage and service frequency are the most highly-ranked transportation service attributes in the HOQ, improving these aspects of the existing bus and train services should be a priority.

Furthermore, long walking distances between bus stops and essential locations are a challenge for the primary personas. Dallas has more than 2000 miles of sidewalk missing (32% of total sidewalks) [77], and abruptly-ending sidewalks, combined with surfaces in disrepair, can put older adults (and any pedestrian) in a dangerous situation. The walkability for older adults living in Dallas is further limited by street/road hybrids where accessibility to essential amenities is disrupted by multi-lane, wide, and high-speed thoroughfares that hinder interactions between people and businesses [78], [79]. Thus, installing and improving sidewalks would help older adults to safely navigate between bus stops; however, in many cases, the distance to transit service is still prohibitive, particularly in the heat of North Texas summers.

In an effort to improve its transit offerings, DART has recently begun offering GoLink, an on-demand point-to-point transit service. This service was initiated as a microtransit system providing noontime transit to corporate employees within the Legacy West zone in Plano (a suburb north of Dallas) and was later expanded to additional areas in North and South Dallas [80]. While GoLink might initially seem to address the needs of the primary personas, further investigation indicates that this is not the case: DART has received complaints that GoLink serves only suburban and upper income areas, and DART officials have confirmed that GoLink was not intended for urban and low income areas as an improvement for fixed-route bus services [80].

In contrast to DART services, taxi and rideshare offer comfort, spontaneity, and short and direct trips. However, these services are not suitable for the primary personas, due to fear of riding with a stranger, lack of assistance, and the cost. An alternative that performed well in the HOQ analysis is private transit service; for example, Envoy[6] and SilverRide[7] are two for-profit companies providing specialized senior transportation for older adults who no longer drive. While SilverRide operates only in Bay Area, Envoy has operations in the Dallas area. However, these companies charge premium prices for their services, making them out of reach for the low-income primary personas.

To address the affordability requirement of the primary personas, a volunteer-based private transit service could be a good transportation solution. For example, ITNAmerica[8] is a non-profit providing ride services for older adults by leveraging volunteer drivers and their cars. However, ITNAmerica does not have an affiliate in Dallas, and while its services are more affordable than Envoy and SilverRide, it is not free of cost. Depending on the purpose, duration, and time of the ride, the price of ITNAmerica services can reach as high as the for-profit companies. A more suitable model for non-driving community-dwelling older adults in Dallas may be borrowed from Drive a Senior[9], which is a purely volunteer-based driving program offering rides to older adults in the Austin, Texas area with five branches. This program relies on volunteer drivers, legacy givers, online fundraising events, and standard donations from individual citizens to sustain their continuous service to older adults free of charge.

[6] https://envoyamerica.com/
[7] https://www.silverride.com/
[8] https://www.itnamerica.org/
[9] https://driveasenior.org/

2.6 Conclusion

The study presented in this paper demonstrates the potential of empirically-derived personas to clearly portray the transportation needs and preferences of the most mobility-vulnerable older adults. Personas incorporate the goals, motivations, and other lifestyle choices of older adults, which provides an advantage over market segmentation approaches that focus on grouping older adults solely by demographic factors. The primary personas identified in this paper provide a common ground for decision making by transportation system stakeholders, including government officials, policymakers, funding agencies, land use planners, transportation providers, and designers. Using the primary personas and HOQ enables a systematic design process to identify holistic transportation solutions without car-dependency that not only serve non-driver older adults but also can help driver older adults to make easier decisions on driving cessation, as well as addressing the transportation challenges of other vulnerable populations.

One limitation of this study is the relatively limited diversity of the survey participants, who are mostly from low-income Black communities. The COVID-19 pandemic prevented the administration of additional survey sessions, but as pandemic restrictions continue to relax, there may be the now possibility of holding focus groups with a more diverse set of older adult participants to validate the primary persona attributes. Additionally, focus groups with older adults who are identified based on the characteristics of the primary personas can provide greater detail on the transportation needs and expectations of the older adults, as well as validating the personas. Other future work includes a more extensive exploration of existing transportation alternatives in Dallas, according to the needs of the primary personas, as well as an assessment of the feasibility of initiating a volunteer-based transportation service in Dallas that is tailored to the primary personas' needs.

The population of the United States is aging, and older adults wish to maintain their active lifestyles and quality of life as they age. In order to enable active aging for older adults, city planners, transportation designers and providers, policymakers, funding agencies, and other stakeholders should work collaboratively to design age-friendly solutions for current and future generations of older adults. Using empirically-derived personas can help support designs that acknowledge the diversity and heterogeneity of older adults, focus on their age-related needs and preferences, and respect their lifestyle choices, while ensuring that the most vulnerable are protected and included in every aspect of community life [81].

CHAPTER 3

A SYSTEMATIC FRAMEWORK FOR DEVELOPING EMPIRICAL PARAMETERS FOR AGENTS USING PERSONAS AND MULTI-CRITERIA DECISION ANALYSIS

3.1 Abstract

One of the ongoing challenges of agent-based modeling is the bottom-up development of realistic agents and estimation of agents' parameters based on empirical data. Developing realistic agents with empirically estimated parameters is especially difficult for agent-based models designed to represent an older adult population. Due to older adults' diversity, vulnerability, inaccessibility, and the inherit complexity of the transportation field, data collection efforts with older adults tend to yield small-scale empirical data with a limited range of information. Therefore, a framework to support the development of empirically-informed agents that realistically represent older adults is needed, particularly for models that are intended to serve as decision support tools with real life deployment.

Data collected from a transportation behavior survey of 167 community-dwelling older adults living in Dallas, Texas, is used to demonstrate how realistic agents can be developed from limited empirical data by generating representative user personas and then leveraging multi-criteria decision analysis to create preference functions for the personas. 1000minds software, which implements *potentially all pairwise rankings of all possible alternatives* (PAPRIKA) decision analysis method was used via role play with the older adult personas. The results of this analysis were then used to inform a preliminary agent-based model that studies older adults' satisfaction with different transportation options. Experimentation with the agent-based model suggests that, while introducing senior-friendly improvements to rideshare and bus services would be valuable, a volunteer driver service could have a far greater positive impact by providing the social connection older adults seek.

3.2 Introduction

Agent-based modeling (ABM) is a computational simulation modeling method which consists of heterogenous individuals (agents) interacting autonomously with each other and their environment, based on their characteristics and independent behaviors in an artificial environment [18], [82]. As a result of these interactions, agents can acquire new knowledge, change their behaviors, and adapt to the changing population dynamics. The motivation for using ABM is the desire to study systems with models having high fidelity to the real world so that the effort to translate the results to the actual world is minimal and the conclusions are convincing [82]. Since agent-based modeling describes a system from the viewpoint of its constituent units, the bottom-up modeling approach is the most important feature of ABM [19]. ABM can enable the testing and development of new theories, as well as aiding in decision-making by providing valuable insights to decision makers at different levels of the system under study [82].

As ABM has shifted from being a niche methodology with an abstract modeling approach to a decision-making tool with real life implications, translation of real-world data into ABM became more critical [83]. The main challenge of ABMs aiding real-life decisions is realistic agent development based on empirical data [84], [85]. When ABM is intended for policy-making decision support, the systematic inclusion of empirical data is necessary, particularly in the creation of agents that realistically represent humans [84]. Although the absence of empirically-driven agents in ABM development may allow modelers to use heuristics or any number of parameters and functions without restricted ranges [86], [87], decision makers may perceive ABMs built in this way as a black box, which can vaporize the credibility – end user's trust – of the model [88]. To avoid this, commonly used approaches to collecting and summarizing empirical data for this purpose include expert knowledge, participant observation, social surveys, interviews, census data, field or lab experiments, role-playing games, and cluster analysis [89].

In recent years, advancements in big data and machine learning have enabled large volumes of data to be incorporated in agent-based modeling. Padilla et. al. [90] provides a structured framework for mining social media data to prioritize preferences of agents, identify world views of agents, and training the agents to learn moving patterns of real people, thereby creating smart agents that can generate their own behaviors by updating their day-to-day activities under varying circumstances. However, the use of big data to create realistic agents for agent-based modeling is context dependent, meaning that adequate data may be only partially available or not available at all for certain populations. This is due to the intrinsic properties – volume and velocity – of big data that requires large

numbers of data in real time. For example, the aging baby-boomer generation tended to resist the rapid development of the Internet, resulting in lower technology adoption and usage rates along with increased concern for their privacy [16]. Therefore, using big data in ABMs to model older adults' behaviors, preferences, and perceptions is nonexistent, since obtaining real time and large-scale data from older adults' activities is close to impossible due to their low engagement with online platforms to reveal their transportation behaviors and decisions. For this reason, the studies to understand older adults' transportation behaviors depend on pen-and-paper and in-person surveys, interviews, and focus groups [6], [16], [27], [48], [91].

The purpose of this study is to introduce a novel systematic framework that characterizes and parameterizes realistic agents when limited data is available from the studied population by integrating empirically-informed user personas with a multi-criteria decision making method known as potentially all pairwise rankings of all possible alternatives (PAPRIKA). The personas used in this study were adopted from previous work [92] in which older adult personas were developed by applying cluster analysis to transportation behavior survey data from community-dwelling older adults living in Dallas, Texas, to identify their characteristics, goals, and motivations. The parameters obtained from PAPRIKA analysis are then used to develop agents for an ABM that demonstrates how older adults' satisfaction levels can be improved with the introduction of senior-friendly transportation improvements.

This paper is structured as follows: Section 3.3 reviews existing literature on agent-based models studying older adults' transportation. Section 3.4 introduces the PAPRIKA method, details the integration of personas into 1000minds software, demonstrates its application, and presents the trade-off results. Section 3.5 describes the development of an ABM with the parameters obtained from PAPRIKA method and demonstrates how it can be used to represent older adults' satisfaction levels with different transportation options.

3.3 Related Work

3.3.1 Agent-based Models of Older Adults' Transportation

Agent-based modeling matured significantly in the last couple of decades where ABM was applied in various research fields, such as social sciences, defense, biology, and marketing [93]. The applications of ABM in transportation domain emerged during the last decade. The use of ABMs to understand urban transportation and mobility issues is relatively new and focuses on sub-categories of urban populations [17]. The existing ABMs in this

field are developed conceptually with synthetic data or partial real data to support policy decisions without actual real world applications [17]. Collecting data to help with understanding of the needs and problems of populations who are using the transportation services in urban settings are extremely expensive and complicated due to the heterogeneity of the transportation users and transportation providers [17]. This obstacle is more challenging with older adults due to their declining physiological and psychological health, which yields in incomplete datasets with low numbers of older adult participation [16]. Therefore, the number of empirical studies using ABM for older adults' transportation and mobility in urban settings is sparse.

Yang et. al. [94] developed a pilot agent-based model to understand the impact of daily transport activities and the neighborhood environment on depression levels of older adults living in urban areas. The model consists of older adults between the ages of 65 and 85 years old, categorized by depression status, gender, income level, driver's license status, car ownership status, and employment status based on a U.S. national prevalence data. The model is built in a hypothetical city with multiple locations representing the residences of older adults, sources of basic needs, and social activities. The neighborhoods in which older adults reside are associated with three arbitrarily assigned values for safety, walkability, and environmental depression risk, which includes other potential factors affecting older adults' depression. A hypothetical bus network serves the downtown area. In the model, older adults are assigned a limited travel time budget to take trips. Their depression is determined to be a weighted function of total non-work trips, walking distance, and environmental depression risk. These weights are assumed to be equal. Three interventions and the combinations of these interventions are introduced to this model to understand their effects on older adults' depression. The first intervention aims to promote walkability by increasing neighborhood safety. The second intervention reduces bus fares. The third intervention increases the number of bus lines. Implementing a single intervention did not alleviate older adults' depression as much as the combination of these interventions. The most effective scenario in reducing older adults' depression were the combination of improved walkability, reduced fares, and increased bus lines.

Yang et. al. [95] adopted the ABM developed by Yang et. al. [94] to examine the impact of free bus policy on older adults' depression levels in England. Two versions of the hypothetical city were used: rich-center and poor-center. Regardless of the segregation scenario, free bus policy increased the bus use and decreased the depression. When the attitude towards the busses was more positive, the rate of bus use was increased more in the poor-center

city than the rich-center city. The degree of attitude towards busses did not affect the older adults' depression levels under free bus policy. The impact of shorter bus wait time was found to increase bus use and decrease the depression. This result was more prominent for low-income older adults in poor-center city.

Zhang et. al. [96] used an exploratory agent-based model to understand older adults' accessibility to oral health screening and treatment facilities via transportation networks in Northern Manhattan, New York City. The purpose of the model is to provide decision support to health planners and policy makers for their endeavors in enabling oral health equity to older adults. The older adults are categorized into four distinct groups based on the form of transportation they use: walk, by car, by bus, or by van. Their oral health status is decided on their age and income. The model was built in a GIS environment to locate oral health clinics and to estimate travel durations and distances. The results demonstrate that the proximity of oral health services impacts older adults' decisions to seek oral health services. The social support in terms of transportation assistance was found to encourage older adults to participate in preventive oral health screenings.

These existing models incorporate fragments of older adults' characteristics from several different sources of data, along with various assumptions made by the modelers. These ABMs lack the realistic bottom-up involvement of older adults' motivations and goals along with their demographics for the population of interest. The reason for this fragmented agent development is the lack of relevant data and the difficulty of conducting in-depth surveys and focus group interviews with older adults.

3.4 Methodology

Older adults make their transportation decisions based on their preferences and perceptions, including limitations due to declining health, demographic factors, and attributes of transportation alternatives [92]. Due to this multifaceted nature of older adults' transportation and mobility, using multicriteria decision making (MCDM) is suitable to understand the dynamics of their decisions.

MCDM is an umbrella term for several methods and the software built on those methods that enables and supports decision making when multiple criteria (or objectives) are required to be considered together in order to rank, prioritize, or choose alternatives by explicitly weighting criteria and trading off between them [97]. MCDM

methods and software have a wide range of applications, such as daily life activities, investment portfolios, and healthcare.

In the literature, there are several studies reviewing and comparing weighting methods for MCDM [98]–[101]. Based on the results of these studies, 1000minds software was selected to determine weights of older adults' transportation preferences. The mathematics behind 1000minds is based on the patented *potentially all pairwise rankings of all possible alternatives (PAPRIKA) method* [102]. In PAPRIKA method, modelers or decision makers perform – in a role play as personas – pairwise trade-offs between older adults' decision-making criteria for their transportation preferences to identify the weights of criteria and utilities of each criterion level via 1000minds[10] software. In the process of working with the software, decisions makers are given two options. Each of these options has the same pair of criteria while the criterion levels differ (i.e., high and low) between the options. The decision makers select one of the options by performing a trade-off between the levels of the criteria.

While 1000minds can be used as a stand-alone decision tool, its strength is the capability to include up to 1000 participants for group decision activities [99] that enables collectively determined weights of criteria. Since 1000minds is web-based software, decision-makers can participate remotely and separately in the trade-off process. An important advantage of this feature is the ability to avoid groupthink in which the decision makers may reach to a consensus under the influence of their peers without critically evaluating the options and the criteria individually. Furthermore, deciding between two options is experienced by everyone in daily life, and therefore, 1000minds is more natural to the human nature compared to other approaches (i.e., analytical hierarchy process (AHP)) in which decision makers are asked "on a scale from 1 to 9, how many times more (or less) important is criterion A than criterion B?" [103], [104]. Thus, decision makers can have more confidence in their decisions, resulting in more accurate criteria weights.

3.4.1 Application of 1000minds

The application of 1000minds was carried out via role play with the primary personas – Elizabeth, Cassandra, and Beatrice – that were developed from a travel behavior survey with 167 community-dwelling older adults in Dallas, Texas [92]. These primary personas are the most vulnerable ones out of 17 personas identified [92], whose

[10] 1000minds.com

transportation needs require immediate attention. The following mobility requirements for the primary personas were identified as independence, walkability, safety, spontaneity, assistance, comfort, flexibility, reliability, accessibility, affordability, and direct and shorter trips.

For MCDM analysis, the identified criteria should be preferentially independent, meaning that the changes in the level of one criterion should not change the levels of another criterion. For this reason, safety is excluded since it is embedded in various aspects of transportation and should not be an item to trade-off. However, one aspect of safety – riding with others – is included in further analysis since it frequently appears in literature as a concern for rideshare, and it does not change the rest of the criteria levels. Similarly, flexibility is excluded since it is not preferentially independent from accessibility and direct and short trips. In addition, walkability, as the most basic transportation option and a vital element of built environment, is also a gateway to other transportation options. Therefore, walkability is not included in the trade-off analysis.

The levels of each criterion are identified based on services of transportation providers [76], [105]–[107] and the characteristics and preferences of the primary personas. The higher ranked levels of each criterion are based on the expectations of the personas and the attributes of potential future improvements in transportation services and novel services that do not operate in Dallas. The levels of each criteria are presented in Table 3.1, Table 3.2, and Table 3.3.

Table 3.1: Levels of affordability, assistance, and reliability

Rank	**Affordability**	
Lowest rank ↓ Highest rank	$20+ (one way)	
	$10-$20 (one way)	
	$5-$10 (one way)	
	$2-$5 (one way)	
	$1-$2 (one way)	
	Free	
Rank	**Assistance**	
Lowest rank ↓ Highest rank	No assistance	- Driver (not trained) does not assist
	Assistance only with information	- Driver (not trained) may assist only with information
	Assistance with information and physical needs	- Driver (trained) assists with information and physical needs - Or there is trained staff responsible to assist older adults other than the driver
Rank	**Reliability**	
Lowest rank ↓ Highest rank	Long wait time	- Frequent route changes and service cancellations - 20-40 min. wait time
	Somewhat long wait time	- Limited vehicle availability at the time of request - Waiting for in-advance scheduled service, other passengers, or waiting in traffic - 10-20 min. wait time
	Somewhat short wait time	- Limited vehicle availability - 5-10 min. wait time
	Very short wait time	- Reserved vehicle in advance - Vehicle at location on time - Slight variation due to traffic - 0-5 min. wait time

Table 3.2: Levels of spontaneity, accessibility to transit and stops, physical comfort in vehicle

Rank	**Spontaneity**	
Lowest rank ↓ Highest rank	Not at all spontaneous	- Schedule/plan 2-4 weeks in advance
	Slightly spontaneous	- Schedule/plan 1-2 weeks in advance
	Moderately spontaneous	- Schedule/plan 3-7 days in advance
	Very spontaneous	- Schedule/plan 1-3 days in advance
	Extremely spontaneous	- Schedule/plan/take the trip within a day or as soon as needed
Rank	**Accessibility to Transit and Stops**	
Lowest rank ↓ Highest rank	Not at all accessible	- Access point to transit 1-1.5 miles away
	Slightly accessible	- Access point to transit 0.75-1 miles away
	Moderately accessible	- Access point to transit 0.5-0.75 miles away
	Very accessible	- Access point to transit 0.25-0.5 miles away
	Extremely accessible	- Access point to transit 0-0.25 miles away
Rank	**Physical Comfort in Vehicle**	
Lowest Rank ↓ Highest Rank	Not at all comfortable	- Vehicle is not clean - No priority seating and no privacy - Seats are uncomfortable - Rides are rough and bumpy - Fast and sudden acceleration and deceleration
	Slightly comfortable	- Occasionally there is trash in vehicle - Priority seating available without privacy - Seats are uncomfortable - Rides can be rough and bumpy - Occasionally fast and sudden acceleration and deceleration
	Moderately comfortable	- Vehicles are clean - Priority seating available - No privacy - Seats are comfortable - Rides are rarely rough and bumpy - Smooth ride
	Very comfortable	- Vehicles are clean - Private seating (vehicle is not shared with others except the driver) - Seats are comfortable - Rides are never rough and bumpy - Smooth ride

Table 3.3 Levels of direct and short trips, and riding with others

Rank	Direct and Short Trips	
Lowest rank ↓ Highest rank	Not at all direct and short	- Driving all around the city to pick up/drop off others - Transiting more than 2 vehicles to get to destination - Trip takes all day
	Somewhat direct and short	- Picking up others only at 2–3-mile radius - Transiting 2 vehicles to get to destination - Trip takes half of the day
	Very direct and short	- Picking up others only at 1–2-mile radius - No need to transit (1 vehicle) - Trip takes 1-2 hours of the day
Rank	**Riding with Others**	
Lowest Rank ↓ Highest Rank	Afraid of riding with others	- Afraid of riding with stranger(s) - Able to ride with familiar and trusted people
	Somewhat afraid of riding with others	- Concerned about riding with strangers but still rides due to lack of another option
	Not afraid of riding with others	- Not afraid of riding with strangers

After the levels for each criterion were determined, each one of the current transportation options (DART bus, DART train, taxi/cab, DART paratransit, rideshare, and riding with family and friends) available to older adults were ranked for each criterion. Although a volunteer driver program to provide transportation for older adults does not currently exist in Dallas, this program was also included as an option in order to capture its value, from the perspective of the primary personas, in comparison to the available transportation options. The ranks of the volunteer driver program were identified from existing programs operating in other parts of the U.S. [107]–[109]. Table 3.4 shows the characteristics of each of the transportation options with respect to each criterion

Table 3.4 Characteristics of each transportation option with respect to each criterion

Transportation Options	Affordability	Assistance	Reliability	Spontaneity	Accessibility to Transit and Stops	Physical Comfort in Vehicle	Direct and Short Trips	Riding with Others
Volunteer driver	Free	Assistance with information and physical needs	Very short wait time	Moderately spontaneous	Extremely accessible	Very comfortable	Very direct and short	Not afraid of riding with others
Riding with family/friends	Free	Assistance with information and physical needs	Somewhat short wait time	Very spontaneous	Extremely accessible	Very comfortable	Very direct and short	Not afraid of riding with others
Rideshare	$10-$20 (one way)	Assistance only with information	Somewhat short wait time	Extremely spontaneous	Extremely accessible	Moderately comfortable	Very direct and short	Somewhat afraid of riding with others
Dart paratransit	$2-$5 (one way)	Assistance with information and physical needs	Somewhat long wait time	Not at all spontaneous	Extremely accessible	Moderately comfortable	Somewhat direct and short	Not afraid of riding with others
Taxi/cab	$20 + (one way)	Assistance only with information	Somewhat long wait time	Very spontaneous	Extremely accessible	Moderately comfortable	Very direct and short	Somewhat afraid of riding with others
Dart Bus	$1-$2 (one way)	No assistance	Long wait time	Moderately spontaneous	Slightly accessible	Slightly comfortable	Not at all direct and short	Afraid of riding with others
Dart Train	$1-$2 (one way)	No assistance	Long wait time	Moderately spontaneous	Not at all accessible	Slightly comfortable	Not at all direct and short	Afraid of riding with others

The next step was to perform trade-offs through role play for each of the primary personas: Elizabeth, Cassandra, and Beatrice. Figure 3.1 demonstrates an example of a trade-off in a role play as Elizabeth. During the execution of the trade-offs in 1000minds software, the decision maker may pick one of the two options based on the characteristics, goals, and motivations of the persona. If the given two options are equally valuable for the persona, the decision maker can mark the trade-off options as equal. If the given two options are not possible logically or the criterion levels of either one of the options cannot be implemented in real life, the decision maker can mark the trade-off as impossible.

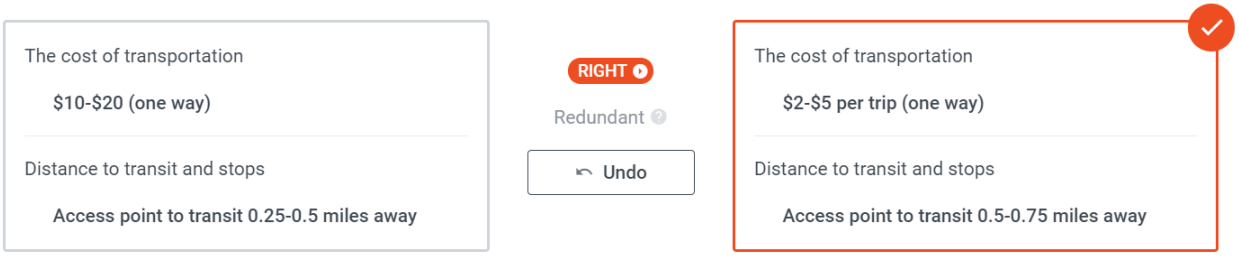


Figure 3.1: Example of a trade-off in 1000minds as Elizabeth

After completing pairwise trade-offs for each primary persona, as shown Figure 3.1, 1000minds provides an accuracy level as a measure of how well the decision model is trained to reflect decision maker's preferences. This accuracy level is calculated by Spearman's rank correlation for the overall ranking of possible options relative to the decision maker's true overall ranking [102]. If this accuracy level is greater than 90%, the weights and utilities of the criteria and the ranked alternatives obtained from the trade-offs can be confidently used in further decisions. Since the accuracy levels of trade-offs for Elizabeth, Cassandra, and Beatrice are 99%, 98%, and 92%, respectively, the weights, scores, utilities, and transportation options ranking obtained from 1000minds can be confidently used for further analysis and decisions.

3.4.2 Results of Pairwise Trade-offs in 1000minds

PAPRIKA algorithm generated values for the weights and utilities of criteria and the scores of each criterion level for each primary persona. These score, weight and utility values are the result of pairwise trade-offs based on the characteristics of transportation options and decision maker's role play as personas, given in Table 3.5, Table 3.6, and Table 3.7. The sequence of criteria for each persona is given in descending order of criteria weights.

Table 3.5 The weights and utilities of Elizabeth's criteria

Criteria	**Criteria Levels**	**Criteria Weight (β) (sum = 1)**	**Score (S) (0-100)**	**Utility (U) (%)**
Accessibility to Transit and Stops	Not at all accessible	0.269	0	0
	Slightly accessible		19.7	5.3
	Moderately accessible		39.3	10.6
	Very accessible		74.6	20.1
	Extremely accessible		100	26.9
Affordability	$20 + (one way)	0.217	0	0
	$10-$20 (one way)		35.3	7.6
	$5-$10 (one way)		68.3	14.8
	$2-$5 (one way)		84.2	18.2
	$1-$2 (one way)		92.8	20.1
	Free		100	21.7
Spontaneity	Not at all spontaneous	0.153	0	0
	Slightly spontaneous		10.2	1.6
	Moderately spontaneous		50	7.6
	Very spontaneous		60.2	9.2
	Extremely spontaneous		100	15.3
Direct and Short Trips	Not at all direct and short	0.14	0	0
	Somewhat direct and short		75.6	10.6
	Very direct and short		100	14
Reliability	Long wait time	0.125	0	0
	Somewhat long wait time		15	1.9
	Somewhat short wait time		76.2	9.5
	Very short wait time		100	12.5
Physical Comfort in Vehicle	Not at all comfortable	0.037	0	0
	Slightly comfortable		25	0.9
	Moderately comfortable		83.3	3.1
	Very comfortable		100	3.7
Riding with Others	Afraid of riding with others	0.034	0	0
	Somewhat afraid of riding with others		45.5	1.6
	Not afraid of riding with others		100	3.4
Assistance	No assistance	0.025	0	0
	Assistance only with information		75	1.9
	Assistance with information and physical needs		100	2.5

Table 3.6 The weights and utilities of Cassandra's criteria

Criteria	**Criteria Levels**	**Criteria Weight (β) (sum = 1)**	**Score (S) (0-100)**	**Utility (U) (%)**
Affordability	$20 + (one way)	0.42	0	0
	$10-$20 (one way)		30.4	12.8
	$5-$10 (one way)		47.8	20.1
	$2-$5 (one way)		65.2	27.4
	$1-$2 (one way)		92.5	38.9
	Free		100	42
Accessibility to Transit and Stops	Not at all accessible	0.175	0	0
	Slightly accessible		32.8	5.7
	Moderately accessible		67.2	11.7
	Very accessible		83.6	14.6
	Extremely accessible		100	17.5
Direct and Short Trips	Not at all direct and short	0.146	0	0
	Somewhat direct and short		39.3	5.7
	Very direct and short		100	14.6
Reliability	Long wait time	0.128	0	0
	Somewhat long wait time		57.1	7.3
	Somewhat short wait time		91.8	11.7
	Very short wait time		100	12.8
Riding with Others	Afraid of riding with others	0.063	0	0
	Somewhat afraid of riding with others		95.8	6
	Not afraid of riding with others		100	6.3
Spontaneity	Not at all spontaneous	0.026	0	0
	Slightly spontaneous		20	0.5
	Moderately spontaneous		40	1
	Very spontaneous		80	2.1
	Extremely spontaneous		100	2.6
Assistance	No assistance	0.021	0	0
	Assistance only with information		25	0.5
	Assistance with information and physical needs		100	2.1
Physical Comfort in Vehicle	Not at all comfortable	0.021	0	0
	Slightly comfortable		25	0.5
	Moderately comfortable		50	1
	Very comfortable		100	2.1

Table 3.7 The weights and utilities of Beatrice's criteria

Criteria	**Criteria Levels**	**Criteria Weight (β) (sum = 1)**	**Score (S) (0-100)**	**Utility (U) (%)**
Assistance	No assistance	0.252	0	0
	Assistance only with information		49.6	12.5
	Assistance with information and physical needs		100	25.2
Accessibility to Transit and Stops	Not at all accessible	0.229	0	0
	Slightly accessible		12.5	2.9
	Moderately accessible		17.9	4.1
	Very accessible		67	15.3
	Extremely accessible		100	22.9
Reliability	Long wait time	0.145	0	0
	Somewhat long wait time		77.5	11.2
	Somewhat short wait time		85.9	12.5
	Very short wait time		100	14.5
Direct and Short Trips	Not at all direct and short	0.125	0	0
	Somewhat direct and short		73.8	9.2
	Very direct and short		100	12.5
Physical Comfort in Vehicle	Not at all comfortable	0.125	0	0
	Slightly comfortable		9.8	1.2
	Moderately comfortable		83.6	10.4
	Very comfortable		100	12.5
Affordability	$20 + (one way)	0.09	0	0
	$10-$20 (one way)		36.4	3.3
	$5-$10 (one way)		61.4	5.5
	$2-$5 (one way)		68.2	6.1
	$1-$2 (one way)		81.8	7.4
	Free		100	9
Spontaneity	Not at all spontaneous	0.031	0	0
	Slightly spontaneous		40	1.2
	Moderately spontaneous		60	1.8
	Very spontaneous		80	2.5
	Extremely spontaneous		100	3.1
Riding with Others	Afraid of riding with others	0.004	0	0
	Somewhat afraid of riding with others		50	0.2
	Not afraid of riding with others		100	0.4

Based on the preferences and utilities of the primary personas for the characteristics of each transportation option, the transportation options can be ranked for each persona. Elizabeth's, Cassandra's, and Beatrice's ranked preferences are presented in Figure 3.2, Figure 3.3, and Figure 3.4, respectively.

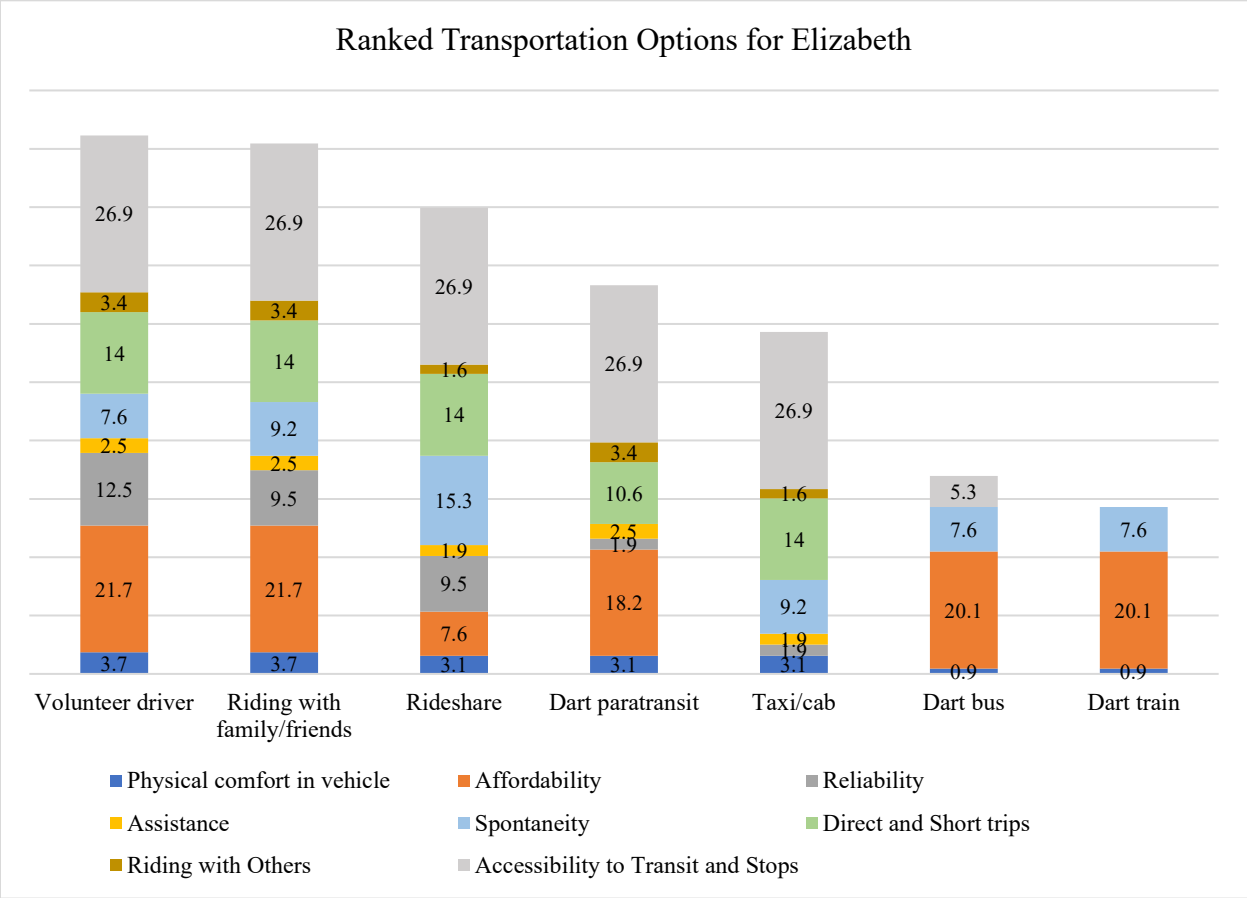


Figure 3.2 Ranked transportation options for Elizabeth

Elizabeth's preferred transportation options are volunteer driver, riding with family/friends, rideshare, DART paratransit, taxi/cab, DART bus, and DART train, respectively. Elizabeth's preference for volunteer driver and riding with family and friends is mainly due to their accessibility, affordability, direct and short trips, reliability, and spontaneity. The costs of rideshare and taxi/cab are limiting factors for Elizabeth's preference of these transportation options. Bus and train fail to fulfill most of Elizabeth's criteria except affordability and spontaneity.

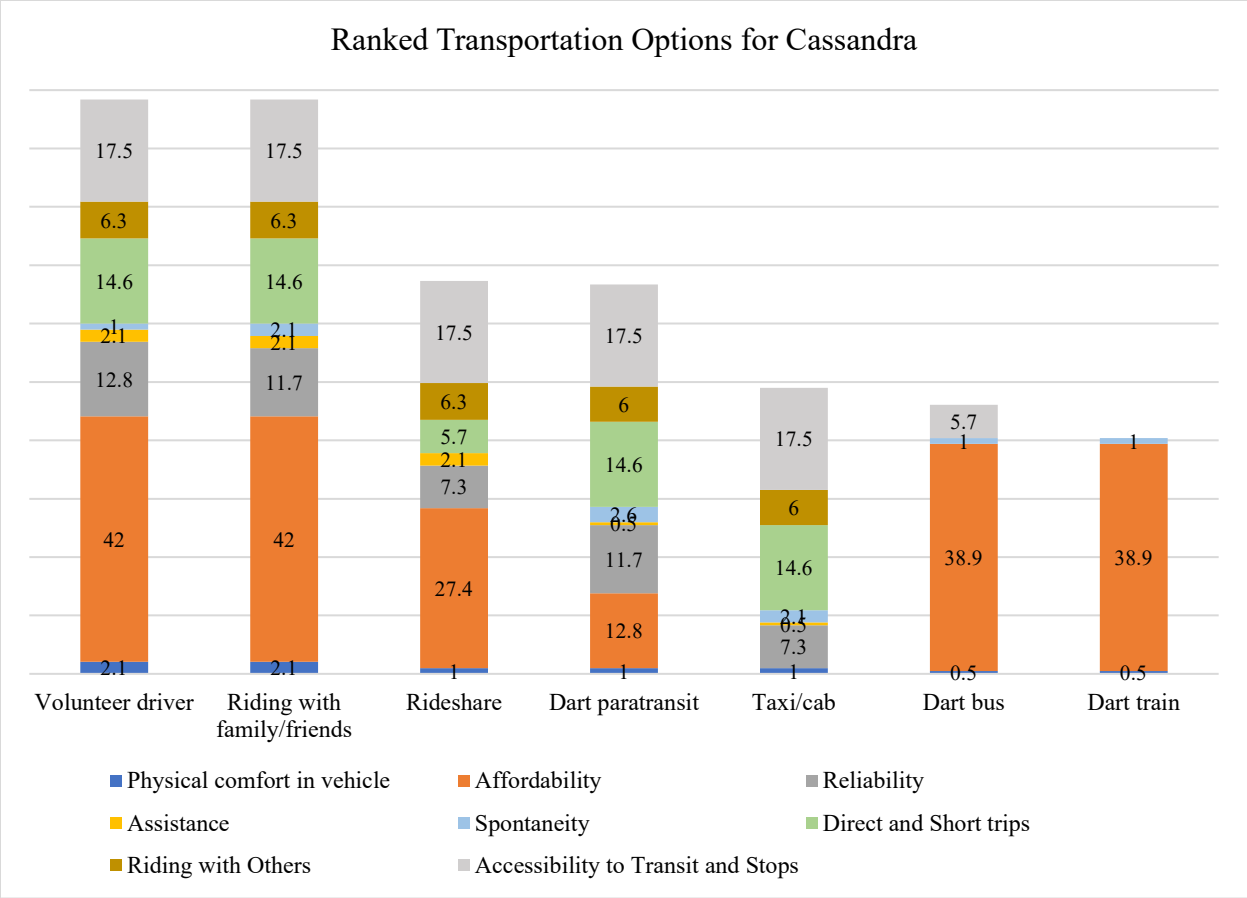


Figure 3.3 Ranked transportation options for Cassandra

Cassandra's preferred transportation options are volunteer driver, riding with family and friends, rideshare, DART paratransit, taxi/cab, DART bus, and DART train, respectively. Cassandra's preference for volunteer driver and riding with family and friends is mainly due to their affordability along with direct and short trips, reliability, accessibility, and feeling more comfortable riding with familiar people. The costs of rideshare, paratransit, and taxi/cab are limiting factors for Cassandra's preference of these transportation options. Bus and train fail to fulfill most of Cassandra's criteria except the affordability.

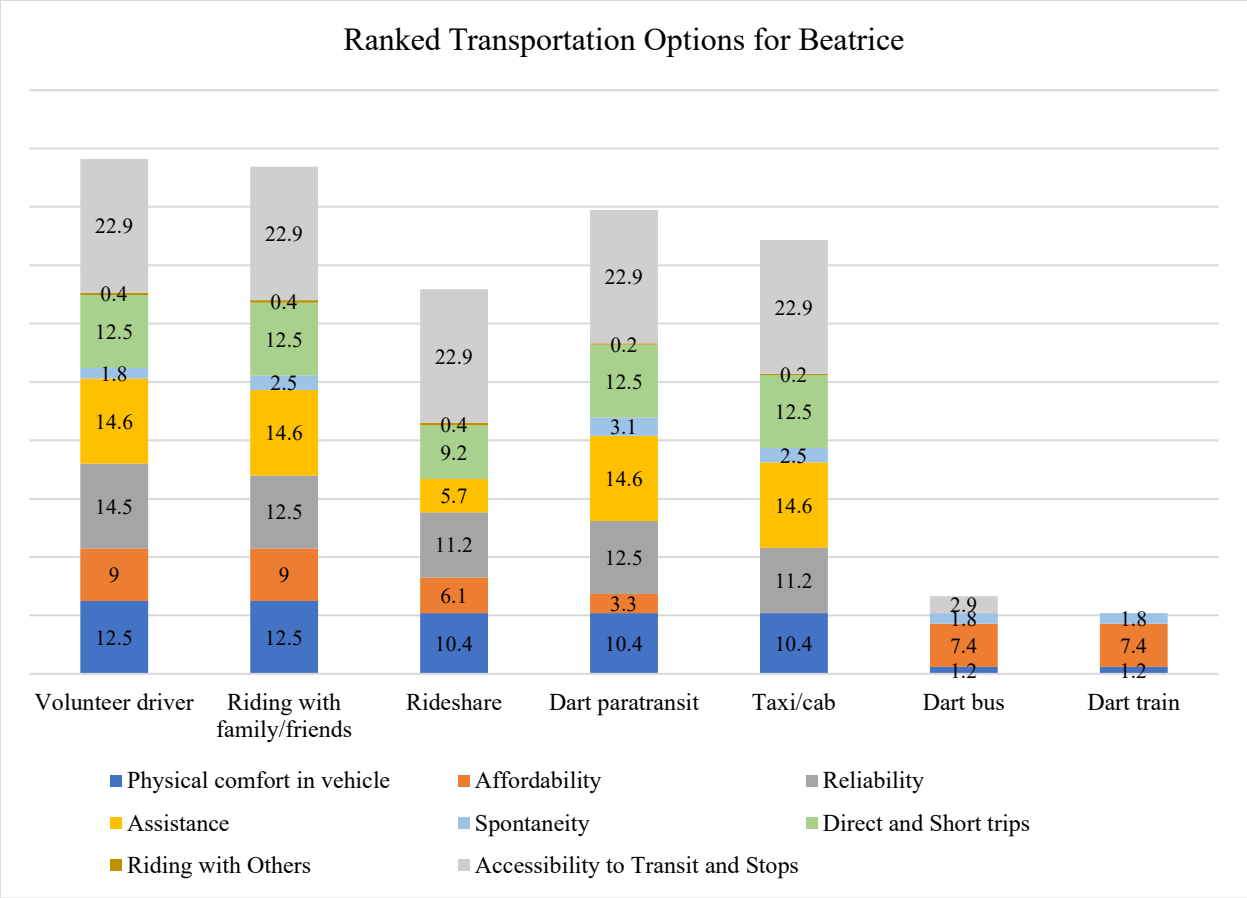


Figure 3.4 Ranked transportation options for Beatrice

Beatrice's preferred transportation options are volunteer driver, riding with family and friends, DART paratransit, taxi/cab, rideshare, DART bus, and DART train, respectively. Beatrice's preference for volunteer driver and riding with family and friends is mainly due to their accessibility, assistance, reliability, physical comfort in vehicle, and direct and short trips. The lack of assistance for rideshare and the cost of taxi/cab are limiting factors for Beatrice's preference of these transportation options. Bus and train fail to fulfill most of Beatrice's criteria except that they are slightly more affordable than non-free options.

3.5 Using 1000minds Results in Agent-based Modeling

The criteria weights and scores identified for the primary personas in the previous section are used to create utility functions as a measure of personas' satisfaction with three transportation mode: volunteer drivers, rideshare service,

and DART bus. The utility values, representing primary personas' satisfaction, are within the range of 0 to 1. The higher the utility values, the more satisfied the primary personas are with their transportation option.

Since the results of PAPRIKA method are to create additive functions, the utility functions are the sum of the satisfaction experienced from each criterion of the transportation option used. Agents' satisfaction from each criterion is dependent on the number of trips taken with each transportation option out of the total number of trips attempted. The satisfaction from each criterion of the given transportation option is also a function of agents' criterion weight and the score of the level of the criterion associated with the transportation option.

Equation 1 presents the general form of the utility function where U is primary personas' satisfaction, and i represents e for Elizabeth, c for Cassandra, and b for Beatrice. Transportation options are represented by t, where t is v for volunteer driver, r for rideshare, and bu for bus. S is the score (scaled down to 0-1 range) of each criterion level for each transportation option. β is the weight of each criterion. Physical comfort in vehicle is represented by ph, affordability by af, reliability by re, assistance by as, spontaneity by sp, direct and short trips by ds, riding with others by ro, and accessibility by ac. Finally, n_{total} and n_t represent the total number of attempted trips and the number of successful trips with the transportation options.

The weight of each criterion (β) for each persona is obtained from PAPRIKA results, shown in Table 3.5, Table 3.6, and Table 3.7. Each criterion level for each transportation option from Table 3.4, and the corresponding scores of each persona (S) from Table 3.5, Table 3.6, and Table 3.7 are used to construct Equation 1 tailored to each persona.

$$U_{i,t} = \beta_{i,ph}\left(S_{i,t,ph} * \frac{n_t}{n_{total}}\right) + \beta_{i,af}\left(S_{i,t,af} * \frac{n_t}{n_{total}}\right) + \beta_{i,re}\left(S_{i,t,re} * \frac{n_t}{n_{total}}\right) + \beta_{i,as}\left(S_{i,t,as} * \frac{n_t}{n_{total}}\right) + \beta_{i,sp}\left(S_{i,t,sp} * \frac{n_t}{n_{total}}\right) + \beta_{i,ds}\left(S_{i,t,ds} * \frac{n_t}{n_{total}}\right) + \beta_{i,ro}\left(S_{i,t.ro} * \frac{n_t}{n_{total}}\right) + \beta_{i,ac}\left(S_{i,t,ac} * \frac{n_t}{n_{total}}\right) \quad \text{(Eq. 1)}$$

Equations 2, 3, and 4 are Elizabeth's utility functions for the volunteer driver, rideshare, and DART bus, respectively.

$$U_{e,v} = 0.037\left(1 * \frac{n_t}{n_{total}}\right) + 0.217\left(1 * \frac{n_t}{n_{total}}\right) + 0.125\left(1 * \frac{n_t}{n_{total}}\right) + 0.025\left(1 * \frac{n_t}{n_{total}}\right) + 0.153\left(0.5 * \frac{n_t}{n_{total}}\right) + 0.140\left(1 * \frac{n_t}{n_{total}}\right) + 0.034\left(1 * \frac{n_t}{n_{total}}\right) + 0.269\left(1 * \frac{n_t}{n_{total}}\right) \quad \text{(Eq. 2)}$$

$$U_{e,r} = 0.037\left(0.833 * \frac{n_t}{n_{total}}\right) + 0.217\left(0.353 * \frac{n_t}{n_{total}}\right) + 0.125\left(0.762 * \frac{n_t}{n_{total}}\right) + 0.025\left(0.75 * \frac{n_t}{n_{total}}\right) + 0.153\left(1 * \frac{n_t}{n_{total}}\right) + 0.140\left(1 * \frac{n_t}{n_{total}}\right) + 0.034\left(0.455 * \frac{n_t}{n_{total}}\right) + 0.269\left(1 * \frac{n_t}{n_{total}}\right) \quad \text{(Eq. 3)}$$

$$U_{e,bu} = 0.037\left(0.25 * \frac{n_t}{n_{total}}\right) + 0.217\left(0.928 * \frac{n_t}{n_{total}}\right) + 0.125\left(0 * \frac{n_t}{n_{total}}\right) + 0.025\left(0 * \frac{n_t}{n_{total}}\right) + 0.153\left(0.5 * \frac{n_t}{n_{total}}\right) + 0.140\left(0 * \frac{n_t}{n_{total}}\right) + 0.034\left(0 * \frac{n_t}{n_{total}}\right) + 0.269\left(0.197 * \frac{n_t}{n_{total}}\right) \quad \text{(Eq. 4)}$$

Equations 5, 6, and 7 are Cassandra's utility functions for the volunteer driver, rideshare, and DART bus, respectively.

$$U_{c,v} = 0.021\left(1 * \frac{n_t}{n_{total}}\right) + 0.420\left(1 * \frac{n_t}{n_{total}}\right) + 0.128\left(1 * \frac{n_t}{n_{total}}\right) + 0.021\left(1 * \frac{n_t}{n_{total}}\right) + 0.026\left(0.4 * \frac{n_t}{n_{total}}\right) + 0.146\left(1 * \frac{n_t}{n_{total}}\right) + 0.063\left(1 * \frac{n_t}{n_{total}}\right) + 0.175\left(1 * \frac{n_t}{n_{total}}\right) \quad \text{(Eq. 5)}$$

$$U_{c,r} = 0.021\left(0.50 * \frac{n_t}{n_{total}}\right) + 0.420\left(0.304 * \frac{n_t}{n_{total}}\right) + 0.128\left(0.918 * \frac{n_t}{n_{total}}\right) + 0.021\left(0.25 * \frac{n_t}{n_{total}}\right) + 0.026\left(1 * \frac{n_t}{n_{total}}\right) + 0.146\left(1 * \frac{n_t}{n_{total}}\right) + 0.063\left(0.958 * \frac{n_t}{n_{total}}\right) + 0.175\left(1 * \frac{n_t}{n_{total}}\right) \quad \text{(Eq. 6)}$$

$$U_{c,bu} = 0.021\left(0.25 * \frac{n_t}{n_{total}}\right) + 0.420\left(0.925 * \frac{n_t}{n_{total}}\right) + 0.128\left(0 * \frac{n_t}{n_{total}}\right) + 0.021\left(0 * \frac{n_t}{n_{total}}\right) + 0.026\left(0.4 * \frac{n_t}{n_{total}}\right) + 0.146\left(0 * \frac{n_t}{n_{total}}\right) + 0.063\left(0 * \frac{n_t}{n_{total}}\right) + 0.175\left(0.328 * \frac{n_t}{n_{total}}\right) \quad \text{(Eq. 7)}$$

Equations 8, 9, and 10 are Beatrice's utility functions for the volunteer driver, rideshare, and DART bus, respectively.

$$U_{b,v} = 0.125\left(1 * \frac{n_t}{n_{total}}\right) + 0.090\left(1 * \frac{n_t}{n_{total}}\right) + 0.145\left(1 * \frac{n_t}{n_{total}}\right) + 0.252\left(1 * \frac{n_t}{n_{total}}\right) + 0.031\left(0.6 * \frac{n_t}{n_{total}}\right) + 0.125\left(1 * \frac{n_t}{n_{total}}\right) + 0.004\left(1 * \frac{n_t}{n_{total}}\right) + 0.229\left(1 * \frac{n_t}{n_{total}}\right) \quad \text{(Eq. 8)}$$

$$U_{b,r} = 0.125\left(0.836 * \frac{n_t}{n_{total}}\right) + 0.090\left(0.364 * \frac{n_t}{n_{total}}\right) + 0.145\left(0.859 * \frac{n_t}{n_{total}}\right) + 0.252\left(0.496 * \frac{n_t}{n_{total}}\right) + 0.031\left(1 * \frac{n_t}{n_{total}}\right) + 0.125\left(1 * \frac{n_t}{n_{total}}\right) + 0.004\left(0.5 * \frac{n_t}{n_{total}}\right) + 0.229\left(1 * \frac{n_t}{n_{total}}\right) \quad \text{(Eq. 9)}$$

$$U_{b,bu} = 0.125\left(0.098 * \frac{n_t}{n_{total}}\right) + 0.090\left(0.818 * \frac{n_t}{n_{total}}\right) + 0.145\left(0 * \frac{n_t}{n_{total}}\right) + 0.252\left(0 * \frac{n_t}{n_{total}}\right) + 0.031\left(0.6 * \frac{n_t}{n_{total}}\right) + 0.125\left(0 * \frac{n_t}{n_{total}}\right) + 0.004\left(0 * \frac{n_t}{n_{total}}\right) + 0.229\left(0.125 * \frac{n_t}{n_{total}}\right) \quad \text{(Eq. 10)}$$

3.5.1 Model Description

A conceptual agent-based model was developed using NetLogo v. 6.2.0. The purpose of the model is to provide better understanding of primary personas' satisfaction with their transportation options in Dallas, Texas. The utility functions are embedded within three agents. Each of the three agents represents a primary persona. The model environment represents an area of 808 square miles including the City of Dallas and the surrounding cities of which the city centers are within 15 miles of Dallas. The origin point of ABM environment represents Downtown Dallas, and the agents' homes are located in accordance with the persona narratives: 5 miles northeast, 10 miles south, and 16 miles north of downtown for Elizabeth, Cassandra, and Beatrice, respectively.

Furthermore, a grocery store location is created for each primary persona, based on the assumption that older adults tend to go to the same grocery store. The locations of the grocery stores are randomly assigned at a proportional distance based on the fact that average household primarily shops at a store 3.79 miles from home [110]. The agents' grocery store trips are scheduled on a monthly basis, and the agents are assumed to make these trips on the same day each month. Therefore, each time-step in ABM corresponds to one day. Each month is assumed to have 30 days, and the model is run for 12 months. Table 3.8 details the monthly schedules of the agents.

Since grocery trips are essential, it is assumed that the agents will go to grocery stores consistently, according to their schedules; however, a 10% allowance is assigned to account for potential trip cancellations due to events such as health issues and hazardous weather conditions. After each simulated trip, each agent will calculate the utility it gained from the trip and will then store this value in its "memory".

Table 3.8 Primary personas' monthly grocery trip schedules

Agents	Monthly Schedule
Elizabeth	1st, 8th, 15th, and 22nd of each month
Cassandra	2nd, 9th, 16th, and 23rd of each month
Beatrice	3rd, 10th, 17th, and 24th of each month

The transportation options in the model are volunteer driver, rideshare, and bus. The reason for volunteer drivers to be included, although there are no volunteer driver programs in Dallas, is to understand the value of a volunteer driver program by observing primary personas' satisfaction with this option. Rideshare is included in the model to assess its current value and a future value after a potential partnership with the City of Dallas and rideshare providers, by observing primary personas' satisfaction with this partnership. The partnership would provide

rideshare services to older adults with more senior friendly features. Similarly, bus service is included in the model to understand the change in older adults' satisfaction between the current bus services and potential improvements to these services.

3.5.2 Experiments

In the first set of experiments, each agent is allowed to use a single transportation option for its grocery trips over 12 simulated months. Their overall utility levels at the end of each simulation run are provided in Figure 3.5.

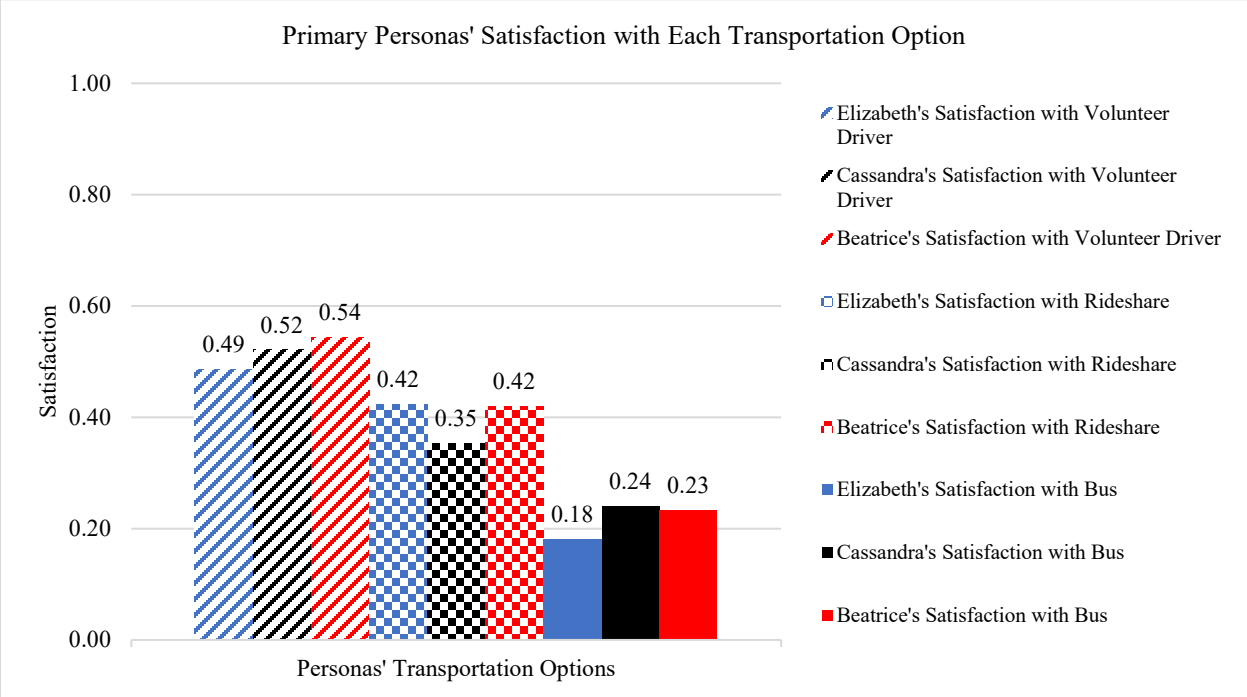


Figure 3.5 Primary Personas' Satisfaction with Each Transportation Option

Elizabeth's, Cassandra's, and Beatrice's satisfaction of riding with a volunteer driver to the grocery store for a year are 0.49, 0.52, and 0.54, respectively. When the primary persona agents use rideshare for their grocery trips, Elizabeth's, Cassandra's, and Beatrice's satisfaction are 0.42, 0.35, and 0.42, respectively. When the primary persona agents go by bus for their grocery trips, Elizabeth's, Cassandra's, and Beatrice's satisfaction are 0.15, 0.24, and 0.23, respectively.

In the second set of experiments, the change in agents' satisfaction levels is observed when improvements to rideshare and bus services are introduced. A potential partnership with the City of Dallas and rideshare providers

is introduced to provide a 50% discount for older adults and trained drivers to help provide information and assist riders with physical needs. Furthermore, new bus routes added with more frequent bus stops, such that wait times for bus services are reduced from 20-40 minutes to 5-10 minutes. These improvements are reflected by increasing the scores, S, of each criterion level to higher levels. Table 3.9, Table 3.10, and Table 3.11 demonstrate the improvements of rideshare and bus services and the changes in related criterion level scores.

Table 3.9 The criterion level score changes for Elizabeth

Elizabeth				
Rideshare				
Criterion	**Previous criterion level**	**Improved criterion level**	**Previous score of the criterion level**	**Improved Score of the criterion level**
Affordability	$10-$20 (one way)	$5-$10 (one way)	0.353	0.683
Assistance	Assistance only with information	Assistance with information and physical needs	0.75	1
Bus				
Criterion	**Previous criterion level**	**Improved criterion level**	**Previous score of the criterion level**	**Improved Score of the criterion level**
Reliability	20-40 min. wait time	5-10 min. wait time	0	0.762
Direct and short trips	- Transiting more than 2 vehicles to get to destination - Trip takes all day	- Transiting 2 vehicles to get to destination - Trip takes half of the day	0	0.756
Accessibility	- Access point to transit 0.75-1 miles away	- Access point to transit 0.25-0.5 miles away	0.197	0.746

Table 3.10 The criterion level score changes for Cassandra

Cassandra				
Rideshare				
Criterion	**Previous criterion level**	**Improved criterion level**	**Previous score of the criterion level**	**Improved Score of the criterion level**
Affordability	$10-$20 (one way)	$5-$10 (one way)	0.304	0.478
Assistance	Assistance only with information	Assistance with information and physical needs	0.25	1
Bus				
Criterion	**Previous criterion level**	**Improved criterion level**	**Previous score of the criterion level**	**Improved Score of the criterion level**
Reliability	20-40 min. wait time	5-10 min. wait time	0	0.918
Direct and short trips	- Transiting more than 2 vehicles to get to destination - Trip takes all day	- Transiting 2 vehicles to get to destination - Trip takes half of the day	0	0.393
Accessibility	- Access point to transit 0.75-1 miles away	- Access point to transit 0.25-0.5 miles away	0.328	0.836

Table 3.11 The criterion level score changes for Beatrice

Beatrice				
Rideshare				
Criterion	**Previous criterion level**	**Improved criterion level**	**Previous score of the criterion level**	**Improved Score of the criterion level**
Affordability	$10-$20 (one way)	$5-$10 (one way)	0.364	0.614
Assistance	Assistance only with information	Assistance with information and physical needs	0.496	1
Bus				
Criterion	**Previous criterion level**	**Improved criterion level**	**Previous score of the criterion level**	**Improved Score of the criterion level**
Reliability	20-40 min. wait time	5-10 min. wait time	0	0.859
Direct and short trips	- Transiting more than 2 vehicles to get to destination - Trip takes all day	- Transiting 2 vehicles to get to destination - Trip takes half of the day	0	0.738
Accessibility	- Access point to transit 0.75-1 miles away	- Access point to transit 0.25-0.5 miles away	0.125	0.67

Figure 3.6 shows the satisfaction of each primary persona for volunteer drivers and improved rideshare and bus services.

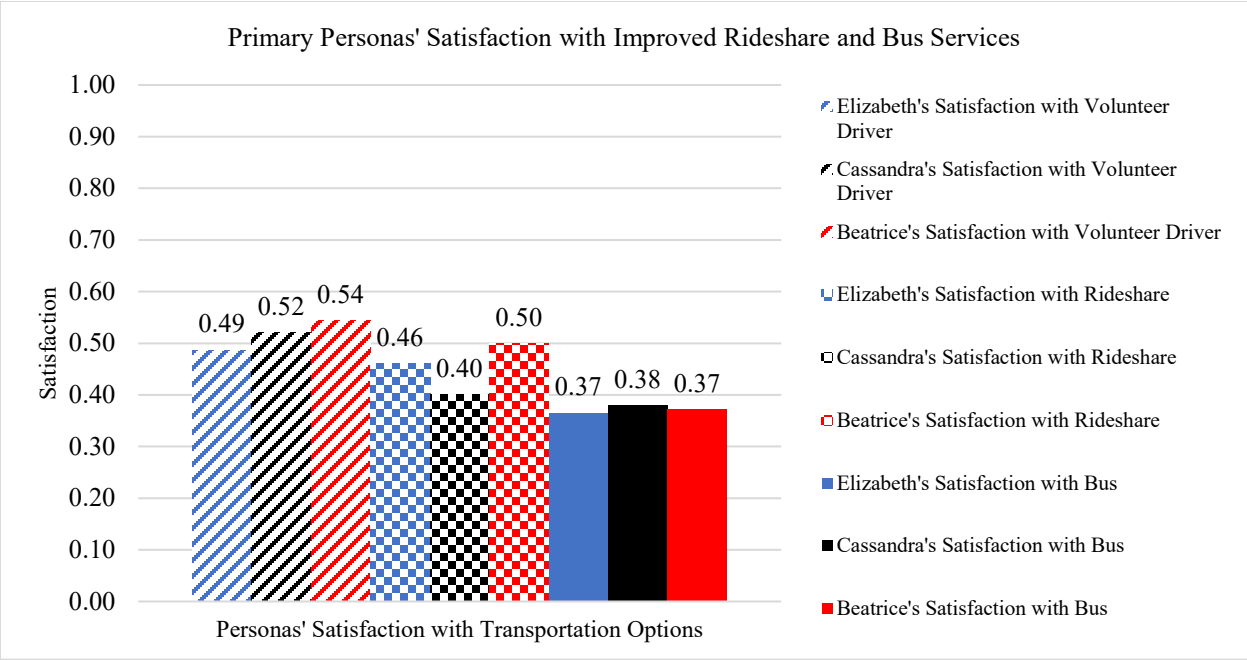


Figure 3.6 Primary Personas' Satisfaction with Improved Rideshare and Bus Services

Elizabeth's, Cassandra's, and Beatrice's satisfaction of riding with a volunteer driver to the grocery store for a year are 0.49, 0.52, and 0.54, respectively. When the primary personas use the improved rideshare option for their grocery trips, Elizabeth's, Cassandra's, and Beatrice's satisfaction are 0.46, 0.40, and 0.50, respectively. When the primary personas use the improved bus service option for their grocery trips, Elizabeth's, Cassandra's, and Beatrice's satisfaction are 0.37, 0.38, and 0.37, respectively.

3.6 Discussion

One of the ongoing challenges of agent-based modeling is the bottom-up development of realistic agents based on empirical data. Addressing this issue is especially important for ABMs designed to aid decisions that have an impact on real people in real life. However, acquiring sufficient and quality empirical data is troublesome, complex, and costly for certain populations due to their vulnerability and inaccessibility. In addition, the context of the decision domain may worsen the difficulty of obtaining empirical data from the vulnerable populations. Older adults are an

example to the vulnerable and inaccessible populations and the decisions regarding their transportation are multifaceted and complex.

As the older adult population grows, their transportation needs diversify due to their heterogenous characteristics, preferences, and motivations. Additionally, collecting sufficient and complete data from older adults is difficult due to their low technology adoption and decline in their physiological and psychological health, which requires face-to-face data collection methods. Therefore, the transportation decision makers and the modelers developing decision tools can face limited data availability, which adds additional barriers and ambiguity to the older adults' transportation decisions.

The existing ABMs studying older adults' transportation build the older adult agents from various sources with fragmented data, heuristics, and assumptions. These studies provide valuable insights to older adults' transportation challenges and directions to creating ABMs as a decision support tool. However, the ABMs developed in these studies are still in the conceptual stage.

This study builds on the older adult personas developed from survey data of 167 community-dwelling older adults in Dallas, Texas [92]. These older adult personas represent several sub-groups of older adults with similar characteristics, preferences, and motivations. While these personas provide a vivid and unifying user model that limits personal assumptions of decision makers and creates a realistic representation of older adults, the decision makers and modelers will still need quantitative parameters to make informed decisions and build models as decision support tools.

This study demonstrates how to quantify older adults' transportation needs and preferences by using the personas in a role play via 1000minds software that implements potentially all pairwise rankings of all possible alternatives (PAPRIKA) method. This method identifies weights and utilities of several criteria that the personas evaluate for their transportation decisions. Furthermore, two options at a time are presented to the decision makers in this role play. One advantage of this pairwise tradeoff between the given two options is the elimination of decision fatigue since the decision makers do not evaluate more than two criteria at a time. Therefore, PAPRIKA method is more natural to the human decision-making process. In addition, the software allows inclusion of multiple decision makers remotely and separately which eliminates groupthink while providing collective results.

Three primary personas represent the most vulnerable older adults from the surveyed sample. Volunteer drivers and riding with family and friends are the most preferred transportation option for all three personas. Following these, rideshare is the third most preferred option for Elizabeth and Cassandra while paratransit is the third most preferred option for Beatrice. Bus and train services are the two least preferred options for all three personas.

For Elizabeth, accessibility to transit and stops, affordability, and spontaneity are the most important criteria, respectively. For Cassandra, affordability, access to transit and stops, and direct and short trips are the most important criteria, respectively. For Beatrice, assistance, accessibility to transit and stops, and reliability are the most important criteria, respectively. The weights and utilities of these criteria along with comfort and riding with others are used to create utility functions as a measure of older adults' satisfaction with their transportation options.

The utility functions are implemented in a conceptual ABM to understand these personas' satisfaction with their transportation options for their grocery trips. The transportation options included in ABM are volunteer driver, rideshare, and bus services. In the first set of experiments, the primary persona agents used each of the transportation options as a single mode. The personas had the most satisfaction with the volunteer driver option, followed by rideshare, and bus.

In the first set of experiments, the agents were given access to only one of the transportation options over the course of a simulated year. At the end of one year, as expected, the agents were most satisfied with the volunteer driver option, followed by rideshare and bus. Elizabeth's utility values from rideshare and bus service were 14% and 63% less than her utility with volunteer drivers. Cassandra's utility values from rideshare and bus service were 32% and 53% less than her utility with volunteer drivers. Beatrice's utility values from rideshare and bus service were 20% and 57% less than her satisfaction with volunteer drivers. The results suggest that riding with familiar people from the community via volunteer driver program may provide the social connection older adults seek. Therefore, starting a volunteer driver program in Dallas, Texas, may add tremendous value to the lives and wellbeing of older adults.

In a second set of experiments, improvements to rideshare and bus services are introduced. In a partnership with City of Dallas, rideshare services included a fleet with trained drivers for assisting older adults, and a 50% discount is given to the older adults. In addition, more frequent services and bus stops and increased area coverage

with additional bus lines are introduced to improve bus services. After these improvements, Elizabeth's, Cassandra's, and Beatrice's satisfaction with rideshare improved by 10%, 14%, and 19%, respectively, compared with the results of the first experiment. Their satisfaction with bus service improved by 105%, 58%, and 61%, respectively.

The results of the experiments demonstrate that each primary persona's utility is different for each transportation option due to their heterogenous characteristics, expectations, motivations, and goals. The degree of change in their satisfaction levels with the service improvements reflects how much these improvements address their expectations from transportation services. In particular, the improvements in rideshare resulted in a greater increase in Cassandra's and Beatrice's satisfaction levels, compared with Elizabeth. Since Elizabeth does not seek assistance from rideshare drivers and she knows how to use rideshare services, her satisfaction level only improved because of the discount. On the other hand, Cassandra and Beatrice are more satisfied with rideshare since the trained drivers are able to accommodate their physical and information needs. While the improvements in bus service resulted in a greater than 50% increase in each of the primary personas' satisfaction levels, Elizabeth benefited more than Cassandra and Beatrice. Adding bus stops and lines resulted in shorter walking distances to access points, which is important for Elizabeth since she is not able to walk more than 0.25 miles at once.

3.7 Conclusion

The methodology introduced in this study provides a systematic framework for developing realistic agents and empirical estimation of agent parameters for agent-based modeling. The main advantage of this framework is its transferability to other contexts and settings while enabling the inclusion of real-life decision makers to the development of the agent-based model.

The volunteer driver program has a potential to be the backbone of older adults' transportation needs in Dallas, Texas. In future studies, when COVID-19 restrictions allow in-person interactions with older adults, additional empirical data is needed to integrate older adults' social networks, connections, and interactions into the conceptual ABM along with the personas of potential volunteer drivers and their decision framework for volunteering.

CHAPTER 4

CONCLUSION

Having and maintaining a standard of living for health and well-being of oneself and of one's family is a human right. Unfortunately, vulnerable populations in both developed and developing countries are not able to sustain a standard of living due to economical disadvantages, racial and ethnical segregation, physical and mental health conditions, homelessness, and simply getting older. In order to alleviate the vulnerability of these populations and to provide an adequate standard of living, their most basic needs must be met. Transportation is the essential link to the resources to address the basic needs of the vulnerable populations. The transportation solutions to alleviate their vulnerability for a better standard of living are multifaceted and the involvement of all levels of government from federal to city, health institutions, non-profits, transportation providers, individual citizens, and many more are required.

This dissertation focuses on addressing the basic needs of older adults by improving their current transportation options and introducing a volunteer driver program. This program leverages individual citizens as volunteer drivers, who are willing to dedicate their vehicles and free time to provide and enable resources to the elderly. The volunteer drivers enable access to resources for older adults by driving them to essential locations, such as grocery stores and doctor appointments, and taking them back to their home locations. This study is modeled in agent-based modeling for Dallas, Texas. The results of this ABM suggested that community-dwelling older adults living in Dallas, Texas would benefit from a community-tailored volunteer driver program and they are happier and more satisfied when riding with volunteer drivers in Dallas, Texas, compared to other transportation options, such as rideshare and bus service.

The main contribution of this dissertation is a systematic framework to empirically develop realistic agents and estimate agent parameters for agent-based modeling. This systematic framework sequences *the Personas Concept, House of Quality, and PAPRIKA method via 1000minds software*, respectively. In addition to having realistic agents and empirically estimated agent parameters at the end of this framework, each step of the framework

provides stand-alone benefits to the decision makers. The personas concept provides a realistic and vivid representation of the end-users of a product or service which unifies decision makers' focus on the needs of these users and reminds them for whom they make decisions. The House of Quality step mathematically connects the voice of the end-users to the voice of the decision makers in the development team of a product or service. Finally, 1000minds enables integration of decision makers' expertise, eliminates decision fatigue under multiple decision criteria, and allows the collaboration of several decision makers by eliminating peer influence on their decisions.

While the systematic framework is demonstrated with older adults in this dissertation, any research requiring empirically-driven realistic agents and parameters for studying other vulnerable populations in the agent-based modeling can utilize this framework. This is achieved thanks to the context independent structure of this framework.

The ABM for older adults' transportation in Dallas, Texas has a potential for real life deployment as a decision support tool to aid transportation decision makers. The conceptual ABM built in this dissertation with realistic agents and empirical parameters can be iteratively improved by including older adults' social networks and interactions, and empirical volunteer driver agents created with the systematic framework developed in this dissertation. In order to provide a starting point for volunteer agent development, the results of an interview the directors of the two volunteer driver programs, Senior Access and Drive a Senior Central Texas in Austin, Texas, are provided in Appendix O.

A collaboration with Civil Engineering or Applied Geography professionals specializing in Geographic Information Systems (GIS) is recommended to obtain GIS data prepared for and compatible with GIS extension of NetLogo software in order to count for actual distances and travel times of older adults' travel activities.

The systematic framework developed in this dissertation is currently being applied to create realistic farmer agents for agent-based modeling under the project *"Social and biophysical models to integrate local food systems, climate dynamics, built forms, and environmental impacts in the urban FEWS nexus"* in Iowa State University of Science and Technology funded by National Science Foundation (# 1855902).

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APPENDICES

5.1 Appendix A: Secondary Persona - Tina

<table>
<tr><td>TINA
  Age:62
Black American</td><td> 
Home Income Social Connections Transportation
Health:  Mobility:  Transportation Options:  </td></tr>
<tr><td colspan="2"><u>About</u>
Tina has a high school degree. She worked as a receptionist for 33 years. Tina currently lives alone in an affordable senior housing that is 4.5 miles northeast of Downtown Dallas. Tina’s current annual household income is $15,500.</td></tr>
<tr><td><u>Health Background</u>
Tina struggled with her weight all her life due to emotional eating, caused by being single and living alone after leaving her parents’ house at a young age.</td><td><u>Health Status</u>
• Unable to walk less than 0.25 miles at once
• Self-perceived physical health rating is good</td></tr>
<tr><td><u>Social Connections</u>
Although Tina does not have close family relationships, she has a good network of friends from the offices she worked at and her current senior housing complex.</td><td><u>Social Status</u>
• Rarely feels lonely and socially isolated</td></tr>
<tr><td><u>Transportation Options</u>
Tina ceased driving since she thinks driving is not necessary for her anymore. She rides in her friends’ cars to go to grocery store, doctor appointments and other errands. While Tina can benefit from special transportation, she is not qualified for it and she finds it pricey as well. She wants to use public transportation, but the closest bus stop is 1.5 miles away. Also, she despises the condition of busses.</td><td><u>Mobility Status</u>
• Prefers to walk with a companion
• Missed trips for activities due to not finding transportation
• Dislikes undermaintained condition of public transportation: trash, wet seats</td></tr>
<tr><td><u>Transportation Information</u>
Tina depends on printed transit schedules. She never goes online for transportation information.</td><td><u>Accessing Transportation Information</u>
• Local aging and faith-based organizations
• Doctor and health care offices
• Friends/Neighbors</td></tr>
<tr><td colspan="2"><u>Goals and Motivation</u>
Tina is aware of the fact that she will not have the option of riding with her friends since her friends may also have difficulties with driving in the near future. Public transportation will be more essential for her trips when she cannot ride with others. Therefore, she wishes to have easier access to public transportation to take all her trips around the city.</td></tr>
<tr><td colspan="2">Satisfied:  Not Satisfied:  Disappointed:  </td></tr>
</table>

5.2 Appendix B: Secondary Persona - Ying

<table>
<tr><td>YING
  Age:77
Asian American</td><td> 
Home Income Social Connections Transportation
Health:  Mobility:  Transportation Options:  </td></tr>
<tr><td colspan="2"><u>About</u>
Ying has a high school degree. She worked together with her husband, Wei, at their tailoring and shoe repair shop for 45 years. Ying currently lives with her husband in an affordable residential apartment complex for seniors that is 11 miles northeast of Downtown Dallas. Ying’s current annual household income is $9,500.</td></tr>
<tr><td><u>Health Background</u>
Ying had a healthy and active life. Walking, home-cooked food, and work life kept her active mentally and physically.</td><td><u>Health Status</u>
• Easily able to walk more than 0.25 miles
• Self-perceived physical health rating is very good</td></tr>
<tr><td><u>Social Connections</u>
Ying spends most of her time with her husband. She has a few friends in the same apartment complex with whom she goes to bible study and gathers for tea to chat in Mandarin.</td><td><u>Social Status</u>
• Never feels lonely and socially isolated</td></tr>
<tr><td><u>Transportation Options</u>
Ying never had a car before. Therefore, she is used to navigate with the available transportation options. She may find single item grocery needs from a close by neighborhood market. For the rest of her needs, she mostly uses public transportation and sometimes rides with others living in the same complex.</td><td><u>Mobility Status</u>
• Walks 30 minutes 5 days a week
• Uses public transportation 4 to 5 times a week</td></tr>
<tr><td><u>Transportation Information</u>
Ying depends on printed transit schedules. She does not use online services for transportation information due to difficulty of reading and understanding English.</td><td><u>Accessing Transportation Information</u>
• Local aging and faith-based organizations
• Doctor and health care offices</td></tr>
<tr><td colspan="2"><u>Goals and Motivation</u>
Ying had close calls to tipping over on sidewalks and lost her balance a few times due to driver’s behaviors while crossing the streets. Therefore, she wants to avoid these situations that can injure her. While she still anticipates using public transportation, she acknowledges the fact that she may depend more on riding with others as she gets older. Regardless, she wishes to continue maintaining and managing her trips by herself or with her husband as she gets older.</td></tr>
<tr><td colspan="2">Satisfied:  Not Satisfied:  Disappointed:  </td></tr>
</table>

5.3 Appendix C: Secondary Persona - Dericia

<table>
<tr><td>DERICIA
  Age:73
Black American</td><td> 
Home Income Social Connections Transportation
Health: Mobility: Transportation Options:</td></tr>
<tr><td colspan="2"><u>About</u>
Dericia has a high school degree. She was a stay-at-home mother. Dericia took jobs on and off to help her husband make the ends meet. Dericia currently lives with her husband and an adult child in a house they own that is 8 miles south of Downtown Dallas. Dericia’s current annual household income is $42,500.</td></tr>
<tr><td><u>Health Background</u>
Dericia had a healthy life without major health issues. She experiences expected decline in her health due to increasing age.</td><td><u>Health Status</u>
• Able to walk more than 0.25 miles
• Self-perceived physical health rating is very good</td></tr>
<tr><td><u>Social Connections</u>
Dericia feels lucky to have her adult daughter and husband around. She has people to talk and ask for help without hesitation. She has couple of good friends with whom she gets together for card and board games once in every few weeks.</td><td><u>Social Status</u>
• Never feels lonely and socially isolated</td></tr>
<tr><td><u>Transportation Options</u>
Dericia stopped driving but she still rides with her husband and daughter. She goes out couple of times a week and her rides take about 45 minutes. She used special transportation once, but she did not like the experience of waiting more than an hour. Dericia has never used taxi and rideshare services. Also, she does not prefer to walk as a means of transportation.</td><td><u>Mobility Status</u>
• Rides with others
• Missed a memorial service when no one was able to give a ride
• Concerned about neighborhood safety and uneven sidewalks which lacks senior friendly facilities</td></tr>
<tr><td><u>Transportation Information</u>
Dericia depends on her family’s transportation knowledge and hears about available services with word of mouth</td><td><u>Accessing Transportation Information</u>
• Family and friends/neighbors
• Doctor and health care offices
• Phonebook</td></tr>
<tr><td colspan="2"><u>Goals and Motivation</u>
Dericia is aware of the fact that she may not have the option of riding with her husband and daughter since her husband may also have difficulties with driving in the near future and her adult daughter may leave the house after finding a job. Public transportation will be more essential for her trips when she cannot ride with others. However, she despises that there is no public transit provided in her area.</td></tr>
<tr><td colspan="2">Satisfied: Not Satisfied: Disappointed:</td></tr>
</table>

5.4 Appendix D: Secondary Persona - Linda

<table>
<tr><td>LINDA
  Age:71
White American</td><td> 
Home Income Social Connections Transportation
Health: Mobility: Transportation Options:</td></tr>
<tr><td colspan="2"><u>About</u>
Linda has a master’s degree in Education. She worked as standardized test developer and retired 5 years ago. Linda currently lives with her husband and an adult child in a house they own that is 20 miles north of Downtown Dallas. Linda’s current annual household income is $100,000.</td></tr>
<tr><td><u>Health Background</u>
Linda had a healthy life without major health issues. She experiences expected decline in her health due to increasing age.</td><td><u>Health Status</u>
• Able to walk more than 0.25 miles
• Self-perceived physical health rating is very good</td></tr>
<tr><td><u>Social Connections</u>
Linda feels lucky to have her adult son and husband around. She has people to talk all the time. She goes to a book club and meets with her friends regularly. Also, she likes to go to libraries to read and browse for material to learn new hobbies. She makes effort to attend aerobics classes in recreational center where she has couple of work out friends.</td><td><u>Social Status</u>
• Never feels lonely and socially isolated
• Active in self-learning and socializing</td></tr>
<tr><td><u>Transportation Options</u>
Linda’s current transportation is driving her personal car. Occasionally, she rides with her husband and son. She drives her car approximately 10 times a week with 20 minutes average trip durations. She would like to take more walks around the neighborhood, but it is not convenient due to lack of sidewalks. She does not use public transportation and special transportation for now. Although Linda does not use rideshare services actively, her son accompanied her to book and use rideshare.</td><td><u>Mobility Status</u>
• Occasionally rides with others
• Never misses event or appointments
• Lack of sidewalks preventing leisure walks around the neighborhood</td></tr>
<tr><td><u>Transportation Information</u>
Linda knows her way around the city. If she needs to go somewhere that she is not sure how to get there, she looks up directions on online maps. In addition, her son helps her if she needs more assistance. Linda is subscribed to AARP magazine and she grabs public transit schedules at doctor offices and church to increase her awareness and knowledge of other transportation options.</td><td><u>Accessing Transportation Information</u>
• Family and friends/neighbors
• Online map resources 1-2 times a week
• Healthcare offices and church for transportation knowledge after driving cessation</td></tr>
<tr><td colspan="2"><u>Goals and Motivation</u>
Linda is aware of the fact that she may have to give up driving in the future and not have the option of riding with her husband and son since her husband may also have difficulties with driving in the near future and her adult son may leave the house. She would like to have senior friendly sidewalks and repairs on the existing ones. Although she is not an active user of public transportation for now, she hears from her friends that reaching to public transit stops and long wait times are challenging. Therefore, she is worried for her mobility in the future while expecting to keep her activities.</td></tr>
<tr><td colspan="2">Satisfied: Not Satisfied: Disappointed:</td></tr>
</table>

5.5 Appendix E: Secondary Persona - Carmen

<table>
<tr><td>CARMEN
  Age:67
Hispanic American</td><td> 
Home Income Social Connections Transportation
Health: Mobility: Transportation Options:</td></tr>
<tr><td colspan="2"><u>About</u>
Carmen has a high school degree. She worked at a university cafeteria. She has been separated from her husband for 30 years. Carmen currently lives with her 91-year-old mother in a house they own that is 3.7 miles east of Downtown Dallas. Linda’s current annual household income is $19,000.</td></tr>
<tr><td><u>Health Background</u>
Carmen had a healthy life without major health issues. She experiences expected decline in her health due to increasing age and responsibilities of taking care of her mother.</td><td><u>Health Status</u>
• Able to walk more than 0.25 miles
• Self-perceived physical health rating is good</td></tr>
<tr><td><u>Social Connections</u>
Carmen has an older son who lives in Dallas area, as well. Her son tries to stay in touch and help Carmen as much as he can. However, as a primary care giver to her mother, Carmen cannot participate in any type of social activities and feels trapped.</td><td><u>Social Status</u>
• Sometimes feels lonely and socially isolated</td></tr>
<tr><td><u>Transportation Options</u>
Carmen’s current transportation is driving her personal car. She drives up to 12 times a week with an average 25 minutes of driving time. Her old car breaks up occasionally, but she has to keep it up since it is the only way to provide transit for her mother. She tries to walk to places when she can to save from gas and prevent being stranded by the side of the road if the car breaks up. Carmen cannot walk long distances as she used to before and worries about her safety. She despises the condition of sidewalks.</td><td><u>Mobility Status</u>
• Missed couple of doctor appointments to take care of her mother
• Unable to walk due to uneven sidewalks and lack of safety</td></tr>
<tr><td><u>Transportation Information</u>
Carmen’s son gave his old smart phone to Carmen and tried to teach how to use the Internet. Carmen rarely uses online map sources. She relies on her own knowledge of directions.</td><td><u>Accessing Transportation Information</u>
• Her son
• Online map resources once a month or less</td></tr>
<tr><td colspan="2"><u>Goals and Motivation</u>
Carmen is aware of the fact that she may have to give up driving in the future and she may still have to take care of her mother. She would like to have assistance for older adults who take care of their parent(s), like herself, so that she can care for herself and maybe have a chance to do other activities.</td></tr>
<tr><td colspan="2">Satisfied: Not Satisfied: Disappointed:</td></tr>
</table>

5.6 Appendix F: Secondary Persona - Shandra

<table>
<tr><td>SHANDRA
  Age:69
Black American</td><td> 
Home Income Social Connections Transportation
Health: Mobility: Transportation Options:</td></tr>
<tr><td colspan="2"><u>About</u>
Shandra has an associate degree in Accounting. She worked as a payroll clerk in a pharmaceutical company. Shandra retired a year ago. She currently lives alone in a house she owns that is 10 miles southeast of Downtown Dallas. Shandra’s current annual household income is $20,000.</td></tr>
<tr><td><u>Health Background</u>
Shandra had a healthy life without major health issues. She experiences expected decline in her health due to increasing age.</td><td><u>Health Status</u>
• Able to walk more than 0.25 miles
• Self-perceived physical health rating is good</td></tr>
<tr><td><u>Social Connections</u>
Although Shandra’s husband passed away two years ago, she was able to cope with the help of her daughter and granddaughter.</td><td><u>Social Status</u>
• Rarely feels lonely and socially isolated</td></tr>
<tr><td><u>Transportation Options</u>
Shandra still drives her personal car. She drives approximately 8 times a week with an average of 34 minutes per trip. She tried to use public transportation to test how to manage her life without a car. However, she finds the public transportation too expensive for the span of service provided. Also, she does not like to walk because dog problems in her area.</td><td><u>Mobility Status</u>
• Concerned about her safety when walking due to stray dogs</td></tr>
<tr><td><u>Transportation Information</u>
Shandra relies on her own knowledge of directions while driving. If she encounters problems, she will reach out to her daughter and granddaughter. She does not use Internet for information or to secure transportation since she does not have a credit card and access to Internet.</td><td><u>Accessing Transportation Information</u>
• Family</td></tr>
<tr><td colspan="2"><u>Goals and Motivation</u>
Shandra is aware of the fact that she may not have the option of driving herself all the time later in her life. She wishes to have public transportation going directly into neighborhoods with more affordable prices. She had a chance to experience rideshare with her daughter. While she thinks that she may not afford the rideshare frequently, she would like to learn how to secure this transit option online in case she needs it for special events and activities.</td></tr>
<tr><td colspan="2">Satisfied: Not Satisfied: Disappointed:</td></tr>
</table>

5.7 Appendix G: Secondary Persona - Ronnell

<table>
<tr><td>RONNELL
  Age:67
Black American</td><td> 
Home Income Social Connections Transportation
Health: Mobility: Transportation Options:</td></tr>
<tr><td colspan="2"><u>About</u>
Ronnell has a high school degree. She was a stay-at-home mother to her two children. She currently lives alone in a house she owns that is 10 miles south of Downtown Dallas. Ronnell’s current annual household income is $18,500.</td></tr>
<tr><td><u>Health Background</u>
Ronnell had a healthy life without major health issues. She experiences expected decline in her health due to increasing age.</td><td><u>Health Status</u>
• Able to walk more than 0.25 miles
• Self-perceived physical health rating is good</td></tr>
<tr><td><u>Social Connections</u>
Ronnell’s husband passed away five years ago. She was able to cope with the help of her daughter and cousins.</td><td><u>Social Status</u>
• Never feels lonely and socially isolated</td></tr>
<tr><td><u>Transportation Options</u>
Ronnell still drives her personal car. She drives approximately 8 times a week with an average of 15 minutes per trip. She is aware of the transit services in her area, and she finds the services insufficient in terms of frequency. She feels anxious while driving because other drivers drive fast. She knows about rideshare and taxi via her daughter, but she is afraid of riding with strangers and finds these services expensive.</td><td><u>Mobility Status</u>
• Panics while driving in high-speed streets and roads due to other driver’s behaviors</td></tr>
<tr><td><u>Transportation Information</u>
Ronnell relies on her own knowledge of directions while driving. She does not use Internet for information or to secure transportation since she does not have access to Internet. She finds technology too difficult. Therefore, she does not go online for any reason.</td><td><u>Accessing Transportation Information</u>
• Family when necessary</td></tr>
<tr><td colspan="2"><u>Goals and Motivation</u>
Ronnell is aware of the fact that she may not have the option of driving herself all the time later in her life. She wishes to have more frequent public transportation with a larger service area so that she can reach to her basic needs when she can no longer drive.</td></tr>
<tr><td colspan="2">Satisfied: Not Satisfied: Disappointed:</td></tr>
</table>

5.8 Appendix H: Secondary Persona - Quisha

<table>
<tr><td>QUISHA
  Age:77
Black American</td><td> 
Home Income Social Connections Transportation
Health: Mobility: Transportation Options:</td></tr>
<tr><td colspan="2"><u>About</u>
Quisha has K-12th grade without a diploma. She was a stay-at-home mother to her two children. She currently lives alone in a house she owns that is 16 miles south of Downtown Dallas. Quisha’s current annual household income is $9,000.</td></tr>
<tr><td><u>Health Background</u>
Quisha has back problems impacting her ability to walk</td><td><u>Health Status</u>
• Have some difficulty with mobility
• Able to walk less than 0.25 miles at once
• Self-perceived physical health rating is good</td></tr>
<tr><td><u>Social Connections</u>
Quisha’s husband passed away ten years ago. She was able to cope with the help of her children. She gained the ability to be sufficient to herself with time.</td><td><u>Social Status</u>
• Never feels lonely and socially isolated</td></tr>
<tr><td><u>Transportation Options</u>
Quisha still drives her personal car. She drives approximately 10 times a week with an average of 35 minutes per trip. She has never used public transportation and other transit options. Driving at nights can be challenging.</td><td><u>Mobility Status</u>
• Dislikes walking
• Hard to drive at night</td></tr>
<tr><td><u>Transportation Information</u>
Quisha relies on her own knowledge of directions while driving. She does not use Internet for information or to secure transportation since she does not have access to Internet. She finds technology too difficult. Therefore, she does not go online for any reason.</td><td><u>Accessing Transportation Information</u>
• Family when necessary</td></tr>
<tr><td colspan="2"><u>Goals and Motivation</u>
Quisha anticipates that she will be able to drive for at least next ten years. She expects gas cards as a financial support. Quisha would like to drive on safer roads with less traffic that are well lit at night.</td></tr>
<tr><td colspan="2">Satisfied: Not Satisfied: Disappointed:</td></tr>
</table>

5.9 Appendix I: Secondary Persona - Lisa

<table>
<tr><td>LISA
  Age:68
White American</td><td> 
Home Income Social Connections Transportation
Health: Mobility: Transportation Options:</td></tr>
<tr><td colspan="2"><u>About</u>
Lisa has MBA. She worked at several non-profits and retired 3 years ago. Lisa currently lives alone in a house she owns that is 3 miles southwest of Downtown Dallas. Lisa’s current annual household income is $70,000.</td></tr>
<tr><td><u>Health Background</u>
Lisa had a healthy life without major health issues. She experiences expected decline in her health due to increasing age.</td><td><u>Health Status</u>
• Able to walk more than 0.25 miles
• Self-perceived physical health rating is very good</td></tr>
<tr><td><u>Social Connections</u>
Lisa separated from her husband 20 years ago. She has close relationship with her two adult children who also live in Dallas area. Lisa is still involved in fund raising activities with multiple non-profits. She likes to go to exhibitions and concerts with her friends. She tries to exercise regularly at recreation center and plays racket ball with her friends. Lisa tries to participate in seniors’ events to learn about resources available to her.</td><td><u>Social Status</u>
• Never feels lonely and socially isolated
• Active in self-improvement and socializing</td></tr>
<tr><td><u>Transportation Options</u>
Lisa’s current transportation is driving her personal car. Occasionally, she rides with her children. She drives her car approximately 12 times a week with 30 minutes average trip durations. She would like to take more walks around the neighborhood, but it is not convenient due to lack of sidewalks. She uses Uber when she does not feel like driving.</td><td><u>Mobility Status</u>
• Occasionally rides with others
• Never misses event or appointments
• Lack of sidewalks preventing leisure walks around the neighborhood</td></tr>
<tr><td><u>Transportation Information</u>
Lisa knows her way around the city. If she needs to go somewhere that she is not sure how to get there, she looks up directions on online maps or navigation on her smartphone. In addition, her children help her if she needs more assistance. Lisa is subscribed to AARP magazine.</td><td><u>Accessing Transportation Information</u>
• Family and friends/neighbors
• Online resources3-6 times a week</td></tr>
<tr><td colspan="2"><u>Goals and Motivation</u>
Lisa expects to drive for a long time. She would like better lit streets for easier driving at night and well-maintained sidewalks. Although she is not an active user of public transportation for now, she knows that bus stops are too far away for her. She wishes improvements with public transportation for all older adults. She wishes free medical transportation for older adults with medical conditions. Lisa expects better communication of transit options from providers with a detailed directory.</td></tr>
<tr><td colspan="2">Satisfied: Not Satisfied: Disappointed:</td></tr>
</table>

5.10 Appendix J: Secondary Persona - Tyrell

<table>
<tr><td>TYRELL
  Age:81
Black American</td><td colspan="2">    
Home Income Social Connections Transportation
Health:  Mobility:  Transportation Options:  </td></tr>
<tr><td colspan="3"><u>About</u>
Tyrell has an associate of art in Business. She worked at various banks. She currently lives alone in a senior living facility that is 15 miles northwest of Downtown Dallas. Tyrell’s current annual household income is $25,000.</td></tr>
<tr><td><u>Health Background</u>
Tyrell experiences decline in her health due to her age. Walking gets harder for her.</td><td colspan="2"><u>Health Status</u>
• Have some difficulty with mobility
• Able to walk less than 0.25 miles at once
• Self-perceived physical health rating is good</td></tr>
<tr><td><u>Social Connections</u>
Tyrell’s husband passed away six years ago. She has a son living out of state and she talks to him multiple times in a week. Tyrell has good circle of friends in the senior living center with whom she enjoys social activities.</td><td colspan="2"><u>Social Status</u>
• Never feels lonely and socially isolated</td></tr>
<tr><td><u>Transportation Options</u>
Tyrell still drives her personal car. She drives approximately 6 times a week with an average of 20 minutes per trip. She tried using special transportation, but she does not like that there are too many pick ups and long rides. She does not use public transportation because bus stops are too far for her. Sometimes she rides in the vans of senior facility.</td><td colspan="2"><u>Mobility Status</u>
• Never walks outside on the ground
• Unable to walk to bus stops
• Dislikes long rides in special transportation</td></tr>
<tr><td><u>Transportation Information</u>
Tyrell relies on her own knowledge of directions while driving. She does not use Internet for information or to secure transportation. She sometimes asks associates in senior living for help or calls her son.</td><td colspan="2"><u>Accessing Transportation Information</u>
• Family
• Associates in senior living facility</td></tr>
<tr><td colspan="3"><u>Goals and Motivation</u>
Tyrell does not see any other transportation option she likes but driving her own car. Since she does not like riding with strangers; therefore, rideshare is not an option for her. Her goal is to take care of herself as much as she can to continue driving.</td></tr>
<tr><td colspan="3">Satisfied:  Not Satisfied:  Disappointed:  </td></tr>
</table>

5.11 Appendix K: Secondary Persona - Wei

<table>
<tr><td>WEI
  Age:78
Asian American</td><td> 
Home Income Social Connections Transportation
Health: Mobility: Transportation Options:</td></tr>
<tr><td colspan="2"><u>About</u>
Wei has a high school degree. He worked together with his wife, Ying, at their tailoring and shoe repair shop for 45 years. Wei currently lives with his wife in an affordable residential apartment complex for seniors that is 11 miles northeast of Downtown Dallas. Wei’s current annual household income is $9,500.</td></tr>
<tr><td><u>Health Background</u>
Wei had a healthy and active life. Walking, home-cooked food, and work life kept him active mentally and physically. Due to straining his eyes for his job, he does not see well and needs prescribed eyeglasses.</td><td><u>Health Status</u>
• Easily able to walk more than 0.25 miles
• Self-perceived physical health rating is good
• Issues with vision</td></tr>
<tr><td><u>Social Connections</u>
Wei spends most of his time with his wife. He has a few friends in the same apartment complex with whom he goes to bible study and gathers for tea and board games, and chats in Mandarin.</td><td><u>Social Status</u>
• Never feels lonely and socially isolated</td></tr>
<tr><td><u>Transportation Options</u>
Wei never had a car before. Therefore, he is used to navigate with the available transportation options. He goes everywhere with his wife Ying. He mostly uses public transportation and sometimes rides with others living in the same complex.</td><td><u>Mobility Status</u>
• Walks 30 minutes 5 days a week
• Uses public transportation 4 to 5 times a week</td></tr>
<tr><td><u>Transportation Information</u>
Wei depends on printed transit schedules with his wife’s assistance. He does not use online services for transportation information due to difficulty of reading and understanding English.</td><td><u>Accessing Transportation Information</u>
• Local aging and faith-based organizations
• Doctor and health care offices</td></tr>
<tr><td colspan="2"><u>Goals and Motivation</u>
Wei had close calls to tipping over on sidewalks with his wife. He may navigate better with audio aid at intersections. While he still anticipates using public transportation, he acknowledges the fact that he may depend more on riding with others as he gets older. Regardless, he wishes to continue maintaining and managing his trips by his wife as he gets older.</td></tr>
<tr><td colspan="2">Satisfied: Not Satisfied: Disappointed:</td></tr>
</table>

5.12 Appendix L: Secondary Persona - Isaiah

<table>
<tr><td>ISAIAH
  Age:71
Black American</td><td> 
Home Income Social Connections Transportation
Health: Mobility: Transportation Options:</td></tr>
<tr><td colspan="2"><u>About</u>
Isaiah has an associate of science degree in Industrial Engineering. He retired six years ago from a manufacturing company. He lives alone in a house he owns that is 5.5 miles southwest of Downtown Dallas. Isaiah has one child. Isaiah’s current annual household income is $53,000.</td></tr>
<tr><td><u>Health Background</u>
Isaiah had a healthy life. He did not have major health issues. He manages his high blood pressure with a prescribed beta blocker.</td><td><u>Health Status</u>
• Able to walk more than 0.25 miles at once
• Self-perceived physical health rating is very good</td></tr>
<tr><td><u>Social Connections</u>
Isaiah’s wife passed away two years ago. He still grieves but also tries to connect with other seniors at local aging organizations. He has a son who lives out-of-state. He talks to his son couple of times in a week but does not see him frequently.</td><td><u>Social Status</u>
• Sometimes feels lonely and socially isolated</td></tr>
<tr><td><u>Transportation Options</u>
Isaiah drives everywhere with his personal car. While he is aware that there is public and special transportation in his area, he foresees that he will be able to drive for some time and will not need to use any of these transportation options in the near future.</td><td><u>Mobility Status</u>
• Never misses any trips, appointments, or events
• Able to travel wherever he wants at anytime</td></tr>
<tr><td><u>Transportation Information</u>
Isaiah has detailed knowledge of roads in Dallas area. If needs to go to a location he has never been to, he will check online map resources before planning his trip.</td><td><u>Accessing Transportation Information</u>
• Checks online map once in every few weeks</td></tr>
<tr><td colspan="2"><u>Goals and Motivation</u>
Isaiah will continue driving until he is not able to. He grabs and reads printed transportation information available in healthcare offices, church, and local aging organizations to get more familiar with his options when he can no longer drive. Isaiah wishes to increase his circle of friends by participating more events with local aging organizations and recreational centers.</td></tr>
<tr><td colspan="2">Satisfied: Not Satisfied: Disappointed:</td></tr>
</table>

5.13 Appendix M: Secondary Persona - John

<table>
<tr><td>JOHN
  Age:73
White American</td><td> 
Home Income Social Connections Transportation
Health:  Mobility:  Transportation Options:  </td></tr>
<tr><td colspan="2"><u>About</u>
John has an associate degree in culinary arts. He worked at various grocery stores and retired 5 years ago. He lives alone in a senior living facility that is 3.5 miles northeast of Downtown Dallas. John’s current annual household income is $22,000.</td></tr>
<tr><td><u>Health Background</u>
John had to stand on his feet a lot for his work and he injured his back. Although he does targeted exercises for his back, walking can be hard at times.</td><td><u>Health Status</u>
• Have some difficulty with mobility
• Able to walk less than 0.25 miles at once
• Self-perceived physical health rating is good</td></tr>
<tr><td><u>Social Connections</u>
John has never married, and he has been living alone since he was 25. He used to spend time with a couple of close friends, but his friends moved closer to their children. John makes effort to socialize in senior events at the senior living facility.</td><td><u>Social Status</u>
• Sometimes feels lonely and socially isolated</td></tr>
<tr><td><u>Transportation Options</u>
John gave up driving due to expenses and unnecessity of owning one. John uses public transportation three times a week on average and his trips take 15 to 20 minutes. However, there are many occasions he had to wait a long time for a bus. Also, he uses the scheduled bus service provided by senior living facility for local shopping. He worries about conditions of sidewalks and intersections since he may need to use an electric wheelchair in the future.</td><td><u>Mobility Status</u>
• Missed a doctor visit due to lack of transportation
• Uneven sidewalks make it harder to walk</td></tr>
<tr><td><u>Transportation Information</u>
John can ask the social worker in the facility about anything. He has an idea on how to secure transportation online, but also he finds it hard to learn from others.</td><td><u>Accessing Transportation Information</u>
• Social worker
• Advertisement
• Friends and neighbors, doctor offices</td></tr>
<tr><td colspan="2"><u>Goals and Motivation</u>
John would like to establish more social connections within the senior living facility and at outside activities. He sometimes wishes to use Uber to go out in the evening, but its cost prevents him from riding with one. He wishes to have more frequent public transit services and a well-maintained environment to prevent injuries and accidents.</td></tr>
<tr><td colspan="2">Satisfied:  Not Satisfied:  Disappointed:  </td></tr>
</table>

5.14 Appendix N: Negative Persona - Michael

<table>
<tr><td>MICHAEL
  Age:65
White American</td><td> 
Home Income Social Connections Transportation
Health: Mobility: Transportation Options:</td></tr>
<tr><td colspan="2"><u>About</u>
Michael has a mechanical engineering degree from Rice University. He lives with his wife in a house they own that is 15 miles northwest of Downtown Dallas. Michael has two children. He expects to retire in the next 2 years. Michael’s current annual household income is $100,000.</td></tr>
<tr><td><u>Health Background</u>
Michael maintained a healthy lifestyle with his wife. He walks 5 to 7 miles every other day and plays tennis with his wife on the weekends. He did not have major health issues all his life, except couple of sports related injuries.</td><td><u>Health Status</u>
• Able to walk 0.25 miles fast
• Self-perceived physical health rating is excellent</td></tr>
<tr><td><u>Social Connections</u>
Since Michael still works as an engineer, he is connected with co-workers. He attends company events with his wife. Their children live and work in Dallas/Fort Worth area and they go to brunches after their church service on Sundays. As recent empty-nesters, Michael and his wife enjoy their company.</td><td><u>Social Status</u>
• Never feels lonely and socially isolated</td></tr>
<tr><td><u>Transportation Options</u>
For Michael, driving his personal car is the only transportation option since he got his driver’s license at 16. He commutes to work every day, and one-way trip is 40 minutes. While he is aware that there is public and special transportation in his area, he foresees that he will be able to drive for a long time and will not need to use any of these transportation options.</td><td><u>Mobility Status</u>
• Never misses any trips, appointments, or events
• Able to travel wherever he wants at anytime
• No need for trip planning rather than accessing driving durations</td></tr>
<tr><td><u>Transportation Information</u>
Since Michael was born in Dallas, he has a detailed knowledge of the roads.</td><td><u>Accessing Transportation Information</u>
• Navigation apps for directions, road closures and traffic status</td></tr>
<tr><td colspan="2"><u>Goals and Motivation</u>
Michael would like to drive as long as he is able to. In the case of losing his ability to drive, he thinks that he can combine walking and public transportation to go to the nearby shopping center where he can find everything he needs for himself and his wife. For other trips, he would probably use rideshare or special transportation and acquire scheduling information from the providers’ websites. However, Michael is very confident that he will not need any other transportation for a long time. He expects improvements on street and outdoor recreational areas for safer walking and biking experience.</td></tr>
<tr><td colspan="2">Satisfied: Not Satisfied: Disappointed:</td></tr>
</table>

5.15 Appendix O: Interview with the Directors of Senior Access and Drive a Senior from Austin, Texas

Background

The volunteer-based transportation for older adults was started by a Ph.D. student in Social Works with the help of a nun. West Austin Care Givers initiated this volunteer program for older adults with 5 local churches, which funded the start-up of this volunteer program. Later, the program was heavily supported by the Robert Wood Johnson Foundation. Senior Access and other Drive a Senior branches were started by a champion person to address family members' or their own transportation needs. Therefore, branches were initiated as neighborhood-based programs rather than a centralized initiative.

The neighborhood-based branching initiated by a champion person used to be the approach to start and develop a volunteer transportation service. However, the current approach of the existing branches is to make decisions based on demographic changes by identifying the people moving in and out of the area. Senior Access works with cities and chambers to identify these demographic changes and the needs of the senior population. After the seniors in need of transportation are identified, Senior Access visits them in person and evaluates their transportation needs.

All operating branches tried to merge to be a single organization. However, the operation and management dynamics of each branch differs from each other. This mainly stems from the differences in seniors' demographics, especially the income levels. Branches serving high-income areas can get funding faster and easier while this is not possible in low-income areas. Therefore, there is a continuous change in low-income areas that forces branches to think out of the box to accommodate the needs of low-income seniors.

Allocation of Funds

Currently, churches are not the main funders of the program anymore. Funds from several other sponsors are allocated to three main categories. 85% of the funds goes to program services: staff and employed drivers. 7% goes to administration, 6% goes to fund raising expenses, and remaining 3% is for miscellaneous expenses. Currently, the funds are also used to pay for employed drivers to take seniors to vaccination hubs.

Why volunteer drivers?

This volunteer-driven transportation service provides one-to-one connection for seniors which other transportation options lack. Public transportation is a hands-off option where seniors have trouble to get on to busses, figuring out routes and schedules, and transiting to different lines. Therefore, the volunteer driver program is a way of addressing seniors' need for extra love and attention.

There are several other reasons for older adults' preference for the volunteer drivers. For example, a new transit system started in Round Rock, Texas and a bus stop was placed in front of a retirement center. However, walking out to the bus stop, waiting in the hot sun, and not having help with carrying bags were some of the reasons that older adults did not use this transportation service. In addition, Senior Access and Drive a Senior connect seniors with other resources such as Meals on Wheels, and in home care. Therefore, their aim is to provide help to seniors at a full spectrum rather than addressing their transportation needs only.

Impact of COVID-19

Before the COVID-19 pandemic, volunteer drivers were retired individuals at an average age of 72 who had time and willingness for volunteering. After the COVID-19 pandemic began, the older volunteer drivers withdrew from driving since they were at risk too and they did not want to serve in order to protect themselves. *Senior Buddy Program* was started due to these circumstances during the COVID-19 pandemic. In this program, Senior Access matched some volunteers with seniors who needed service. These volunteers call the seniors once or twice a week to check on them. Also, the volunteers, who are willing to go out, provide service by picking up the groceries or prescriptions of the seniors and deliver to their homes rather than taking them out to shops, pharmacies, and other places.

During the pandemic, Senior Access started to recruit at schools to involve students, who have service requirements to complete their degrees, in volunteering as drivers. Before the pandemic, students were not aware of the needs of the seniors unless they had grandparents and older parents to take care. As a result of the pandemic, the needs of seniors became more salient, and people became more aware of the importance of addressing the needs of seniors. Anecdotally, the only positive thing about COVID-19 is that seniors became popular.

The second group of people who have started to volunteer during the pandemic are people working from home. However, due to their limited time in their schedules, these people select trips that are shorter in distance and time. This happens through an online system in which volunteers check the platform to see pick-up and drop-off locations and the estimated duration of the trip. Then, these work-at-home volunteers select the ride based on the convenience.

A small number of stay-at-home mothers are another group to volunteer as drivers during the pandemic. These mothers try to show their kids the importance of giving back to the community and they generally drive seniors along with their kids.

During COVID-19, seniors are allowed one medical ride per week and one grocery shopping trip ride per week to either their local HEB or Walmart. The capacity of vans is normally 14, but during the pandemic, the capacity is reduced by half.

The director of Senior Access said that, "We have lost over 500 clients due to depression during the pandemic because of the social isolation. Circumstances of COVID-19 caused these deaths not the virus."

Reach out Strategies

Both Senior Access and Drive a Senior follow a holistic approach to reach out to potential volunteers and both target every age group with a push-out strategy on social media platforms and radio ads. The social media platform, Nextdoor, is the most effective way to get volunteers involved since it provides an easier and more effective outreach to people in neighborhoods. In addition, Senior Access sends texts to reach out to more potential volunteers since texting has a higher response rate. However, Senior Access does not prefer to send emails and printed brochures to people due to a high discard rate and a high potential for scams.

Overall, reaching out to seniors is not as involved as reaching out to volunteers. Senior Access never had to advertise to seniors. Getting knowledge about the volunteer driver program is via word of mouth for senior riders. Occasionally, awareness campaigns are held for seniors. However, the main strategy of Senior Access is to campaign for people and places that the seniors will reach out for help, such as churches, senior centers, and doctor offices. In addition, Senior Access uses the 211 system in which all doctors, hospitals, and churches look for resources when a senior reaches out to them for help. When seniors are in need, they will reach out to either their

loved ones and friends, or entities they trust and have familiarity. Therefore, when providing transportation to older adults, the aspect of trust, safety, and familiarity should be the top priorities.

Impact of Volunteer Driver Absence on Senior Riders

Seniors are never denied a ride if they ask for it. Regardless of the fact that the ride may be scheduled in advance or there is a same-day request, Senior Access and Drive a Senior will try to get a volunteer driver as fast as they can. However, if a volunteer driver cannot be found for the requested time and day, a rideshare is scheduled and paid for the senior from the funds of the branches. While Senior Access has a reimbursement grant that pays 80% of the rideshare costs back during the pandemic, the remaining 20% is paid from the funds of Senior Access.

Volunteer Requirements

Volunteers are not required to serve a minimum number of hours, unlike ITNAmerica. Volunteers are encouraged to ride once a month or more if they can. However, volunteering should not be a requirement by setting a minimum limit for service. If volunteering is forced, it will not be enjoyable for the volunteers. People would be better volunteers if they wanted to do it rather than forced to do it. In addition, volunteering should be made as easy as possible for the volunteers.

Volunteer Participation

Nowadays, people prefer to volunteer in churches, but they do not stem out to volunteer in other places. Previously, 60% of the incoming people to volunteer as drivers were from churches, this rate is now 2%.

Generally, once a volunteer participates, it is likely that the volunteer will come back again. However, it is more important to have a small number of volunteers participating continuously rather than a high number of volunteers participating only once.

Eligibility to Use the Volunteer Driver Program

To benefit from volunteer driver services, seniors must reside within the branch boundaries. Trips are not limited to branch boundaries. However, there are limits to how far seniors can get a ride. This distance limit is decided based on the distance between the branch boundaries seniors reside and the locations of the medical facilities, since Austin

is notorious about the distances to reach to medical facilities. This may be totally different for other cities. Additionally, trips with 50 to 100 miles distance are not undertaken since these trips are a lot to ask from volunteers.

Van Rides

Seniors prefer riding in the vans over single car rides. Riding in a van is a means of not only getting to the places but also socializing with other seniors during the ride. Therefore, riding with other seniors provides social connection. These rides are also a way of getting out for seniors since they do not have other options to get out of their homes. Anecdotally, seniors sometimes go to Walmart just to get out and socialize, and they may buy only one item.

Vans are driven by paid employees. During the initial phases of the program, volunteers drove the vans. However, when a scheduling issue occurs with the volunteer driving the van, up to 14 seniors' schedules and trips are cancelled or delayed. Therefore, Senior Access stopped using volunteers as van drivers and hired van drivers as Senior Access employees.

Trip Chaining

Trip chaining is possible with an advance notice. Waiting time between the locations is the limiting factor in trip chains. If the amount of waiting time is unknown or long, seniors are accommodated with one-way trips for both directions with different volunteers. Or, if volunteers are willing, they can run their own errands during the waiting time and go back to pick up the senior after receiving a call for pick-up. Volunteers make the decision for one-way or round trip after assessing the convenience of the waiting time. In addition, some seniors may go to the same place around the same times in a day. If this happens, volunteers can pick up two or three seniors. During these processes, volunteers have access to pictures of seniors via the Senior Access portal to identify the seniors for pick-ups.

Regular Trips with the Same Volunteer Driver

Seniors may ask for the same driver for regular trips if both the senior and the volunteer connect with each other. Unfortunately, seniors sometimes may try to take advantage of this connection by calling the volunteer and requesting other trips and tasks that are not scheduled via the online platform. Similarly, the senior and the volunteer may dislike each other. In either case, if there is a complaint, a block between the volunteer and the senior is added on the online platform so that Senior Access knows not to match them.

Reasons for not getting along:

- Personalities
- Non-stop talking senior where volunteering becomes overwhelming for the volunteer
- Aggressive driving or speeding
- Seniors sometimes ask a lot from volunteers

Purposes of the Rides

Before introducing van rides, 70% of rides were for medical reasons and 30% for other reasons. After starting van rides, seniors started to travel together and meet their social needs this way. As a result, social isolation started to go away, and interestingly, the rates of doctor trips dropped significantly. The director of Senior Access concluded that the seniors were going to doctors to socialize.

Before COVID-19, van rides were also used for going to senior centers. Social aspects of van rides changed the rates of trip purposes. Trips to grocery stores and senior centers were 65% of the rides and 35% for medical rides. During the pandemic, the medical rides are prioritized. Therefore, statistics look different compared to pre-pandemic numbers. While vans still operate during the pandemic, the main purpose is to take seniors to get vaccinated.

Days and Times of The Rides

While the days of the trips depend on the seniors, 98% of the trips take place on weekdays, and 2% take place on weekends. These weekend trips are mainly for going to churches and beauty shops.

Seniors are encouraged to schedule their trips between 10 am and 2 pm if the location is far from their homes. There is more flexibility with the times of rides for closer locations. Senior Access and Drive a Senior do not get requests for special trips such as weddings and airport drop-off/pick-up, but if the volunteer and the senior have a good relationship, these types of trips may happen. However, the region Senior Access covers has low-income seniors and they generally do not take these kinds of special trips due to their income levels.

Impact of Demographics on Using Volunteer Drivers

Low-income seniors use volunteer drivers more often and start using at a younger age than higher income seniors. The reason is that higher-income seniors have a hard time giving up their cars because they expect it to be their only form of transportation. On the other hand, low-income seniors either did not have a car before using volunteer drivers or they had an unreliable car. Therefore, they are used to being dependent on other transportation options to reach to their destinations.

White senior population used to be 75% of the clients of Senior Access, and the remaining 25% were Blacks, Hispanics, and Asians. However, after outreaching to Black communities, these demographics had a major shift. Currently, 50% of clients are White, 25% Black, 20% Hispanic, and 5% are from other races.

According to the director of Senior Access, Black and Hispanic communities have trust issues. The issue is not because they do not trust the service. These communities are more family oriented and receive care from other family members. The trust issue may be getting help from strangers. Similarly, Black seniors have trust issues since there was no one to help them in the past but their own families. The Director of Senior Access stated that the key to reaching out to seniors in minority communities is to connect with trusted people of these minority communities.

The Reasons for Seniors to Ride with Volunteer Drivers

The main reason seniors stop driving and start riding with volunteers is that they lose their reflexes and cannot promptly react to situations in traffic. Seniors using volunteer drivers have low to mid income levels, living off of social security and retirement. Some seniors with low incomes residing within the boundaries of Senior Access had to give up their car because they could not afford healthcare. Additionally, seniors do not want to burden their families with their needs to go to places. Even though seniors live with family members, the family does not necessarily help. Volunteers are encouraged to not be judgmental since they do not know the family history of the senior. Therefore, there are a lot of seniors who do not want to ask their kids for help but also their kids may not or do not want to help. In addition, there are seniors who recently moved to the area to be close to family, but since the family members work, they still have no one to help them.

Additional reasons for seniors to use volunteer drivers over other transportation options:

- It takes too long to go to places with public transportation or other pick-up services having routes

- Seniors cannot go to their destinations directly with fixed route transportation options. They have to go around the city, wait, and pick-up other people
- $1.75 charge for a ticket is too much for the seniors if they have to use metro/rail
- Understanding, navigating the routes, and transitioning between different routes is too hard for them. Even if they seek help from people working in hubs/stations, they do not remember what they are supposed to do (which line to take, at which stop to switch lines, at which stop to get out, etc.)

The Reasons for Volunteers to Participate as Drivers

Volunteer drivers' motivation depend on their age. The best volunteers are retired men who want to do something, get to know people, and enjoy giving back to the community. They are the group of volunteers that seniors are less likely to complain about their driving. The second group of volunteers are stay-at-home mothers teaching their kids about giving back to their community. The third group of volunteers are people working at home, who are in their 40s to 50s. They volunteer with Senior Access if they are given a day off for volunteering or if they can squeeze it in their schedule.

The Director of Senior Access hypothesizes that some volunteers may avoid serving certain areas because of the racial makeup of the area. This cannot be validated.

Demographics of Volunteer Drivers

According to Senior Access, only 15% of volunteers are Hispanics and less than 2% are Black volunteers, and the rest is White volunteers. Students can volunteer as a volunteer driver as well. However, their motivation is due to meeting a service requirement in order to satisfy their degree. Student volunteers have no income. Working individuals have mid-range incomes. Since retired volunteers are able to participate, it can be said that they are healthy enough to drive safely and have enough to maintain a car.