Vehicle Travel and Ownership among the US Older Adults in the Digital Era

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This project examines the interaction of the built environment, travel behavior, and technology usage among older adults. Decades-long transportation policies favoring vehicle owners have made many older adults disadvantaged in daily travel. Studies and policies specifically addressing older adults' travel needs do not keep pace with the increasing number and diversity of the aging population.</td></tr>
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Chapter 1. *Introduction*

1.1. Introduction

The number of older adults in the U.S. is increasing rapidly due to the aging baby boomers, those born between the years of 1946 and 1964. The population aged 55 and over increased from nearly 60 million in 2000 to more than 90 million in 2019. People aged 65 and over have increased by approximately 15 million from 2000 to 2019. More than 15% of the United States population in 2019 were aged 65 and over in 2019. The U.S. Census Bureau predicts that by 2034, there will be approximately 78 million people aged 65 and older, outnumbering those 18 years of age and under (U.S. Census Bureau, 2019).

The rapidly increasing older adults in the United States has posed significant challenges for transportation planning and urban planning in general. In the next decades, most older people will be baby boomers, born in an era of rapid suburbanization and highway expansion. However, most older adults live in low-density areas without ready access to shopping centers, hospitals, and senior centers. Moreover, the number of socioeconomically disadvantaged older adults, such as those who live alone, racial minorities, and retirees with low incomes, is growing rapidly. It implies that older adults with difficulties driving, owning, or maintaining vehicles will drastically increase in the coming decade.

Given the vehicle dependence among older adults, aging in place can only be achieved among a limited number of older adults. In this dissertation, I define aging in place as a condition where older adults can access their daily social, health, recreational, and other activities freely through motorized or non-motorized transportation or virtual means, e.g., online shopping, independently. Those who experience unmet needs to access daily activities, e.g., have missed health trips, are defined as stuck in place. From an equity perspective, future transportation planning should enable every older adult to age in place. However, it is unclear in the planning scholarship and practice about which older adults are stuck in place, and how to empower them with the right to age in place through planning policies.

The decades-long transportation planning practice in the U.S. has prioritized system-wide mobility, making those with car ownership and driving difficulties disadvantaged in daily travel. Many older adults, especially those having income and health challenges, fall into the disadvantaged groups. The nation has recognized the importance of providing transportation services for older adults since the 1960s. However, these policies did not fully address the challenges to reduce older adults' travel difficulties. First, born in the massive highway development and suburbanization age, many people of the baby boomer generation have different lifestyles than the previous generations. They are also influenced more by technology development than the previous generations. How this demographic change might impact the travel demands of older adults is not clearly addressed by current policies.

Second, federal funding programs such as paratransit and public transit fare reduction have neither effectively nor cost-efficiently resolved transportation problems for the aging populations, especially those who live in the suburbs. As the number of car-dependent older adults increases rapidly, it is crucial to understand their travel difficulties and the potential policy changes to address these difficulties.

Third, older adults can use various technology tools and platforms to supplement or replace their daily travel in a digital era. Despite the potential impacts of various forms of technology on daily travel demand and infrastructure design, policies have rarely addressed the role of technology-based solutions in tackling older adults' travel difficulties. While certain applications, such as online shopping and e-banking, can replace some out-of-home activities for older adults, other forms of technology, including transportation planning applications and ride-hailing services, encourage older adults to travel more smartly.

For this project, I ask the following overarching questions: What are the travel characteristics of older adults and near older adults in a digital era? Which social groups have more difficulties in daily travel? How should policies change to address these challenges? In this report, I define older adults as those aged 65 and older and near older adults as those aged 55–64. Since many people aged 55–64 start to experience declining health and prepare for retirement, I also include this age group to more thoroughly understand the transportation needs of the aging population. Answering these questions would inform the policymakers of the overlooked and unmet transportation needs of older adults, thereby helping them seize the opportunity of the infrastructure investment to advance age-friendly transportation systems, communities, and cities with the help of other government sectors, non-profit agencies, and private companies.

To this end, I ask three interrelated questions:

- How does the baby boomers' current daily travel differ from that of the silent generation's twenty years ago?
- Who are the older adults that are having vehicle ownership difficulties? What factors are related to these difficulties?
- Does information communication technology (ICT) increase older adults' daily travel? If so, for whom and which activities?

1.2. An Interdisciplinary Perspective to Understand Transportation Planning for Older Adults

In this project, I approach transportation planning for older adults from the social exclusion lens. I join a growing number of transportation scholars and sociologists (Lucas, 2012; Sheller, 2018) that argue that transportation is a human right and essential in determining people's social and economic well-being. People who do not have adequate transportation resources and easy access to transportation facilities experience increased difficulties engaging in necessary social and economic activities, e.g., employment, education, and healthcare.

From the perspective of activity engagement, two aspects other than transportation are crucial in mitigating socioeconomically disadvantaged people's transportation difficulties: land use characteristics and technology usage. The residential built environment can reshape people's daily travel, and the new technology, such as online shopping and ride-hailing services, can assist older adults to participate in various activities.

The interaction of transportation, land use, and technology in advancing activity participation is a new perspective to understanding older adults' quality of life, health, and social engagement. Various gerontology and public health theories provide rich theoretical evidence to better understand how these three interrelated systems contribute to older adults' subjective well-being. In this project, I regard transportation, neighborhood built environment, and technology as determinants of health, contributing to successful and capable aging.

This project builds upon the theories in different disciplines and broadly discusses the intersection of travel behavior, residential location, and technology usage among older adults based on various areas of transportation planning and interdisciplinary theories and methods.

1.3. An Overview and Chapters

This project employs descriptive analysis, econometric modeling by combining spatial data, national-level cross-sectional and panel data, and a survey of 2,510 older adults in order to examine the interplay of the built environment, vehicle ownership and usage, and technology usage among U.S. older adults. In the following paragraphs, I overview the main contents of each chapter.

As the first research chapter, Chapter 2 investigates how today's older adults travel differently from older adults at the beginning of the millennium. The generational differences of vehicle travel are interesting, given that the baby boomer generation is well accepted as a generation of car lovers. Does their vehicle travel differ from people of the same age in the early 2000s, when smartphones and other technology were not as prevalent as today? A quasi-panel design using the 2001 and 2017 National Household Travel Survey (NHTS) reveals no evidence for this question, controlling for other factors. Additionally, baby boomers who live in the suburbs do not travel more than suburbanites in the early 2000s.

In a vehicle-dependent world, having a vehicle is still necessary for most older adults in low-density areas. In Chapter 3, I use the 2017 NHTS to examine residential location and vehicle ownership decisions among older people. I conceptualize *stuck in place* as a situation where older adults living in low-density areas but having no vehicles. The results demonstrate that households headed by retirees, low-income older people, and women living alone were more likely to be *stuck in place*. All else being equal, age itself is not a predictor of being stuck in place. However, age is a strong predictor for segments of socioeconomically disadvantaged older adults in becoming stuck in place, including retirees and women living alone.

Using the technological tools can potentially increase older adults' ability to participate in daily activities. In the digital era, accessibility can also be achieved by virtual means. Can ICT reduce travel difficulties for older adults? I did not find a survey that holistically collected daily travel and ICT activities among older adults. Therefore, I conducted a survey in Chapter 4 on 2,510 U.S. older adults to answer this question. Results show a mixed answer to the question. Overall, those who used ICT less also traveled less. In particular, older adults with low incomes and less education, older adults who lived alone, and older African Americans had lower daily vehicle travel and more difficulties using most technology applications. However, some applications, for example, online social activities and food delivery, can replace offline activities. Health and social technology applications can also reduce the difficulties in daily travel for people of color and those with medical conditions.

The dissertation concludes in Chapter 5, the final part, with a summary of key findings, particularly the implications for urban planning policies for a more sustainable, equitable future to enhance every older adult's social and health outcomes. The results inform that advancing transportation support for older adults should consider the diverse travel needs of the increasing number of older adults, especially those in the suburbs that depend on vehicles. In addition, other planning and social policies, e.g., narrowing the digital divide to make technology accessible to all and promoting walkable and accessible communities, help older adults benefit equitably through increased opportunities to access daily destinations in the digital era.

1.4. Contributions

This project is based on multiple disciplines' theories, empirical studies, and methods. It contributes to the scholarship and policymaking in transportation planning and policies for older adults in at least three ways. First and most importantly, the project revisits older adults' transportation service provisions in the U.S. and highlights the overlooked needs of older adults. The baby boomer generation will dominate the aging population in the United States in the next two decades. Though they are portrayed as car lovers in social media, the analysis finds that their travel patterns are far more heterogeneous than that image. Given the social diversity of this generation, the number of older adults disadvantaged in daily travel is increasing rapidly, especially those having difficulties driving and maintaining vehicles. This situation poses substantial challenges to providing transportation services for older adults, especially those who live in low-density suburbs.

Second, each research chapter has individual contributions to a specific line of literature in transportation planning. Each chapter's purpose is to fill the gaps in a line of transportation planning literature regardless of age, and then use the scholarship in gerontology, or other disciplines, regarding the behavior of older adults to show why the research topics are crucial in multiple disciplines. In particular, I am interested in whether findings on older adults are different from those for people of all ages. For example, Chapter 2 builds on the literature about the generational effect of transportation and older adults' travel behavior. I find that the baby boomer generation may not have a higher rate of vehicle travel than people of the same age two decades ago. This finding differs from the current literature on baby boomers, mostly conducted two decades ago when the baby boomer generation was between 35 and 55 years of age. For another example, Chapter 4 builds on the literature about the relationship between ICT and transportation. The gerontology and communication studies literature show that the age-based digital divide is prominent. However, the current planning literature overlooks the relationship between ICT and travel among the aging population. Consistent with the current literature on people of all ages, the results show that online shopping complements traditional shopping trips among older adults. However, social media usage replaces, to some extent, social trips among older adults. This dynamic differs from the current finding on the relationship between online and offline social activities among young people.

Finally, from the policy perspective, results of this project have implications for transportation and non-transportation policies to help older adults mitigate travel difficulties. This report suggests that the federal and local transportation agencies need to work with other related agencies to collectively promote the social engagement of older adults and help every older adult to age in place. The *Bipartisan Infrastructure Law* mentions increasing investments in transportation programs for older adults and technology infrastructure to narrow the digital divide. The findings of this project are fundamental for the Department of Transportation, Department of Health and Human Services, and non-profit agencies like AARP to collaborate and reform planning policies for the U.S.' increasing older adult population.

Chapter 2. *How do Baby Boomers Travel Differently than the Silent Generation?*

2.1. Introduction

Baby boomers, born between 1946 and 1964, were born in the massive suburbanization era and are among the second largest demographic generation in the U.S. Their travel demand and preferences will play a pivotal role in future transportation planning in an aging society. Since this decade will witness even the youngest baby boomers turning 65, transportation and urban planners, social workers, and policymakers must understand older adults' heterogeneous needs and the potential changes to accommodate older adults in a country where most places are vehicle-dependent.

Many scholars and policymakers predict that the upcoming older adults will depend more heavily on vehicles than older adults decades ago (Coughlin & D'Ambrosio, 2012; McGuckin & Lynott, 2012), as today's older adults are wealthier and healthier than decades ago, and more of today's older adults age in the suburbs.

However, this argument might overlook the role of lifestyle changes and socioeconomic diversity of today's older adults. First of all, baby boomers are aging, and might have less travel demand as they age like previous generations. Second, many older adults' lifestyles and daily time usage have been reshaped by Information Communication Technology (Pew Research Center, 2017). For example, online shopping and social media might replace some out-of-home activities. Moreover, many older adults stay in the labor force longer, limiting their time for non-work travel. The population of older adults is dramatically increasing, and with it the number of older adults in poverty and those having medical conditions. These income and health limitations reduce older adults' vehicle ownership and usage, restricting their ability to travel (Rosenbloom, 2001, 2009).

Depending on the past studies on generation and travel behavior and travel behavior of the older adults, this chapter aims to: (a) compare the travel behavior, especially vehicle travel of baby boomers compared to people at the same age in the silent generation (those born between 1928 and 1945); and (b) examine how boomers living in different locations, in various life stages, and socioeconomic groups differ from those in the silent generation.

Understanding older adults' travel complexity and how their travel pattern differs from decades ago is fundamental to transportation planning and policies in the U.S. First, given the large number of baby boomers have been significantly enlarged the amount of older adults, the vehicle travel and carbon emissions will tremendously increase even if baby boomers' vehicle travel is not so different from people of the same age in the silent generation. In this way, planners may hope to seize the opportunity to promote sustainable transportation among the baby boomers, especially among those living in the suburbs.

Second, not every older adult is born and ages in the same way. Older adults who have more difficulties in daily travel, including those with medical conditions, and those who are people of color, might have more difficulties in daily travel. Therefore, it is crucial to understand whether baby boomers with those traits have more travel difficulties, and provide targeted transportation support for them.

2.2. **Literature Review**

This section reviews past literature explaining how baby boomers' travel behavior might differ from the silent generation in two parts: the first part concerns "whether": three effects (aging, generation, and period) were reviewed to overview the uncertainties of baby boomers' travel behavior changes. The second part centers on the complexity by summarizing how the segments of baby boomers might travel differently than people of the same age in the silent generation.

2.2.1. Uncertainties: The Aging, Generation, and Period effects

The Aging Effect

The aging effect holds that people's travel demand will decline with age. As a result of declines in health and income, many older adults experienced a reduction of out-of-home travel (Nordbakke, 2013; Rosenbloom, 1988, 2001). African Americans (Park et al., 2010; Probst et al., 2007; Sikder & Pinjari, 2012), women (Collia et al., 2003; Rosenbloom & Herbel, 2009), those who live alone (Rosenbloom, 2004) and those who live in families with low incomes (Lindstrom-Forneri et al., 2010; Nordbakke, 2013) are among the older adults that have even more travel difficulties in their daily travel. Probst et al. (2007) further noted that older African-Americans were more likely to have long-term immobility than other races, especially when they got older and developed medical conditions. Rosenbloom (2004) observed that when they were widowed and lost their driving ability, older women experienced more difficulties in vehicle travel than their male counterparts.

The Generation Effect

Putting older adults of different generations together may mask the generational differences in travel pattern changes. Generational theory in demography claims a social generation shares common attitudes and lifestyles as they were born in similar social environments and share similar living experiences (Mannheim, 1952; Schuman & Scott, 1989). The most dramatic change among older adults is that the baby boomer generation has replaced older generations as the dominant generation. Baby boomers were born during the massive suburbanization and interstate highway construction. Based on previous literature (Macfarlane et al., 2015; Smart & Klein, 2018b; Weinberger & Goetzke, 2010), those who grew up in neighborhoods and cities with lower densities and less developed transit systems tended to depend more heavily on cars later in life. If boomers' travel and residential preferences carry forward towards their later lives, they may possibly have more vehicle trips than older cohorts, even after retirement.

Scholars have shown interestingly mixed results on the travel behavior changes of older adults over time. Using multiple-year surveys spanning from 1998 to 2013 in Montreal, Canada,

Fordham et al. (2017) determined that younger generations had fewer vehicle trips than older generations when they were aged 50 and older. Buehler & Nobis (2010) compared the travel behavior of those aged 65 and over in the early 1980s and early 2000s in the U.S. and Germany. They noted that older adults in both countries made more trips in 2000 than two decades ago.
Only a few studies have directly addressed the generational changes in baby boomers' travel behavior. The most relevant study (Siren & Haustein, 2016) came from Denmark, which used two waves of data, from 2009 and 2012, of people born in 1946 and 1947, and revealed that retirement was a transitional time for boomers in travel behavior. Boomers' car travel declined, but leisure trips by car increased after retirement. However, this study did not compare whether this change differed from the previous generation, and its sample size, 864 people, was too small to generalize reliable results for policy implications. A study in Australia compared the rate of drivers' license possession at age 60 among generational cohorts (Koppel & Berecki-Gisolf, 2015). Results detailed that at the age of 60, possessing a driver's license was more prevalent among baby boomers than the previous generation. While 96% of those born between 1946 and 1955 had driver's licenses, only 88% of those born between 1936 and 1945 were license holders when 60 years old.

Numerous other studies, primarily using cross-sectional data collected in the 1990s and 2000s, also suggested that boomers travel differently from previous generations. Studies using national and regional travel surveys tended to agree that in Western countries, boomers were healthier than earlier generations and tended to have more vehicle trips and greater vehicle travel distance than all other generations (Goulias et al., 2007; Koppel & Berecki-Gisolf, 2015; McGuckin & Lynott, 2012; Miranda-Moreno & Lee-Gosselin, 2008; Newbold & Scott, 2017; Rosenbloom, 2001; Siren & Haustein, 2016). For example, McGuckin & Lynott (2012) used multiple waves of United States NHTS (1969-2009) and learned that the baby boomer generation had the highest average vehicle travel distance among all generations. Using a panel study from 2002 to 2005, Miranda-Moreno & Lee-Gosselin (2008) observed that baby boomers were the only generation whose out-of-home activity participation increased over time.

The Period Effect

Though lacking direct evidence, current studies have suggested that baby boomers' travel levels might be greater or less than people at the same age in the early 2000s. On the one hand, boomers are generally healthier and wealthier than previous generations, implying that a large number of them experience driving cessation, i.e., giving up driving due to deteriorating health, later than the previous generations (Coughlin, 2009; Rosenbloom, 2009). Studies in North America and Europe further demonstrated that baby boomers who turned 65 years old relied more heavily on automobiles than people of the same age in younger generations (Collia et al., 2003; Newbold & Scott, 2017). One study in Australia found that boomers' vehicle travel was steady over time, though their transit use increased by a small rate (Currie & Delbosc, 2010). Therefore, healthy boomers who could afford cars as they age may have more vehicle trips than older cohorts.

On the other hand, today's social and technological environments are experiencing unprecedented flux, which may lead to a shift in older adults' vehicle usage patterns. Compared to older cohorts, boomers may have more accepting attitudes towards modern technologies and use online platforms or ride-hailing services to replace vehicle travel. For example, using the 2017 NHTS, Mitra et al. (2019) found that more educated, wealthier, and younger older adults were more likely to use ride-hailing applications. Though not a direct link to boomers' technology use and vehicle use, some recent work had attributed millennials' declined vehicle travel in the past two decades partly to the use of modern technologies, replacing vehicle travel with online services (Blumenberg et al., 2016; McDonald, 2015; K. Wang & Akar, 2020; X. Wang, 2019). Wang & Akar (2020) uncovered that the reduced vehicle miles traveled from 2001 to 2017 were not exclusive to those aged 21–36 (millennials in 2017), but also for those aged 53– 71 (boomers in 2017). Another study further noted that economic reasons can explain vehicle ownership changes among young adults. Millennials are more likely to own vehicles when they get economically independent from their parents (Klein & Smart, 2017a).

2.2.2. Complexity of Travel Among Baby Boomers

The three effects discussed before focuses on how an average baby boomer might travel differently than a person at the same age in the silent generation. However, baby boomers are socioeconomically diverse, and current studies suggest the need to further explore how different segments among baby boomers might travel differently from the previous generation based on the life stage, residential location, and demographic and economic attributes.

The Life Stage

Retirement is a tipping point for older adults to change their travel patterns, but the role of retirement in vehicle travel is inconclusive in the existing literature. It is also unclear how retirement influences baby boomers differently than the previous generation. Some studies have suggested that older adults may have more difficulties owning and driving cars after retirement, and as a result, their vehicle ownership and usage decline after retirement (D. Ding et al., 2014; Oakil et al., 2014). Some other studies have noted that while retirement is related to reduced commuting and work-related vehicle trips, non-work trips for leisure, shopping, and social purposes increased after retirement (Berg et al., 2014; Hjorthol et al., 2010; Siren & Haustein, 2016). Vehicle travel may also increase for those who move to retirement communities after retirement. One study in Boston has found that residents living in retirement communities generated more vehicle trips than those living in non-retirement communities (Zegras et al., 2012). They further maintained that social environment attributes, such as social networks, which may initiate trips for social purposes, played a more important role than the built environment attributes.

The Residential Location

The built environment is also associated with boomers' vehicle travel, but how the role is associated with vehicle travel over time is not clear. Some studies have found that baby boomers and other older people who lived near the transit stations in downtown areas in the U.S. made shorter car trips (Boschmann & Brady, 2013; J. S. Lee et al., 2014). Some recent studies have also found that older urban dwellers used ride-hailing services more frequently than those living in suburban and rural areas (Mitra et al., 2019; Shirgaokar et al., 2021), implying that urbanites who have cars might use their vehicles less frequently due to the ride-hailing services. A recent conceptual paper (Golant, 2019) suggested that suburbanite boomers may not rely more heavily on automobiles than people of the same age two decades ago as they could use various online services or ride-hailing services to replace vehicle trips. However, no prior study has examined whether and how boomers living in different locations travel differently than those in the silent generation.

Demographic and Socioeconomic Attributes

Boomers also differ from the older cohorts by their greater demographic and socioeconomic diversities. As reviewed before, people of color, women, and people with low incomes among older people might have additional travel difficulties than non-Hispanic whites, men, and people with higher incomes. Whether racial minorities, women, or boomers with low income have similar or even less vehicle travel than those in the same age decades ago is not clear in the current literature. The decline in boomers' vehicle travel may partly indicate the increasing difficulties of vehicle travel among the transport disadvantaged in older adults.

2.2.3. Research Gaps

The above review documents that it is not clear how older adults, especially the baby boomer generation, travel differently from people at the same age decades ago. Furthermore, it is unclear how baby boomers at different stages, living in different places, and with different social traits travel differently from people of the same age in the silent generation.

A common drawback of the current studies, as Miranda-Moreno & Lee-Gosselin (2008) pointed out, is the failure to sort out the age effect from the generation effect. Using cross-sectional data sets, most of the cited literature had compared boomers' vehicle travel with other age groups. This approach does not indicate whether boomers' unique travel patterns are due to their middle age or generational characteristics. Data in the current literature were primarily conducted before 2010, when most boomers were younger than 55. Therefore, it is also unclear whether baby boomers' travel behavior will still be different from their previous generations when they are 55 and older. A better understanding of these uncertainties needs repeated cross-sectional data or longitudinal data after 2010.

2.3. Research Design

The uncertainties of baby boomers' travel changes unfolded in the past section demonstrate the necessity to investigate the differences in vehicle travel among baby boomers and people of the same age decades ago, i.e., the silent generation. In particular, I am interested in the following question: To what extent are these two generations' diverse demographic and socioeconomic attributes, residential locations, and lifestyles associated with their vehicle travel changes? In answering these questions, the 2001 and 2017 NHTS were used to examine the vehicle travel characteristics of those aged 56–71 in 2001 and 2017 with descriptive analysis and regression models.

2.3.1 Data and Measurements

Based on the Pew Research Center's definition (Dimock, 2019), the silent generation, is defined as those born between 1928 and 1945. Baby boomers refer to those born between 1946 and 1964. As shown in Table 2.1, people aged 56–71 morphed from the silent generation to baby boomers from 2001 to 2017. Since the silent generation and older cohorts have much smaller population sizes than the baby boomer generation, the generational change of older cohorts and travel behavior changes is less relevant to the current chapter. Therefore, I will not consider those aged over 71.

Table 2.1 Generational change of those aged 56–71, 2001–2017

<table>
<tr><th></th><th>2001</th><th>2009</th><th>2017</th><th>Change (01-09)</th><th>Change (01-17)</th></tr>
<tr><td>56–63</td><td rowspan="2">Silent generation</td><td>Baby boomers</td><td rowspan="2">Baby boomers</td><td colspan="2">Generation change</td></tr>
<tr><td>64–71</td><td>Silent generation</td><td>No generation change</td><td>Generation change</td></tr>
</table>

Data Sources

In this study, how boomers' vehicle travel differs from people at the same age in the silent generation and how various factors are related to the generational differences are examined using the 2001 and 2017 NHTS. The Appendix A details the differences of NHTS in different survey years and its potential impacts on the analysis. It also shows the descriptive statistics of samples (Table A-1, Appendix A). The chapter focuses on those aged 56–71 in 2001 and 2017 for several reasons. First, all people in this age group were the silent generation in 2001, but baby boomers in 2017. Second, the data in 2001 and 2017 are more comparable in the economic environment since people of all ages were experiencing economic downturns in 2009 and might have less vehicle travel than other times due to financial constraints. Third, this group includes both those older and younger than 65, which helps describe the role of retirement and the age effect on travel behavior for boomers and the silent generation.

Measuring Outcome Variables

Three measurements were used to examine generational changes in vehicle travel: the frequency of vehicle trips, personal vehicle miles traveled (VMT) per day, and the average distance of vehicle trips. Like Wang (2019), daily personal VMT rather than the more conventional definition of VMT used by the Federal Highway Administration (2018) was applied in this chapter. Personal VMT, similar to personal miles traveled (PMT), better captures a person's daily out-of-home vehicle travel intensity. Older people who lost their abilities to drive still rely on vehicles, asking their family members, friends, or volunteer drivers for help. However, this measurement will double count vehicle travel if the traveler is not driving alone. Whether an older person has commuting trips or not significantly influences their daily time use and travel patterns. Therefore, the VMT for all trips and non-work trips were analyzed.

Measuring Independent Variables

Based on the literature review, other individual-level variables available in 2001 and 2017 NHTS were used to examine vehicle travel changes among older people as a result of generational changes. These variables include:

Demographic factors: age, gender, and race/ethnicity were included. People older than 65 may have different travel patterns as younger people, as this age is related to health declines and retirement. As for race and ethnicity, every surveyed sample were categorized into one of the following: Non-Hispanic whites, African Americans, other races, and Hispanics. Previous studies have found African Americans (Park et al., 2010; Probst et al., 2007; Sikder & Pinjari, 2012) and females (Collia et al., 2003; Rosenbloom & Herbel, 2009) among older people have fewer vehicle trips and travel distances.

Socioeconomic attributes: The annual household income and maximum educational attainment were used to denote the surveyed sample's sociodemographic characteristics. Previous studies have found that low-income and low-educated people among older adults tend to have less vehicle travel (Lindstrom-Forneri et al., 2010; Nordbakke, 2013). The annual household income in 2001 was transformed to comparable units as 2017 U.S. dollars based on the annual average Consumer Price Index (U.S. Bureau of Labor Statistics, n.d.). Income is the weighted household annual income in U.S. dollars adjusted for the household size by dividing the income by the square root of household size (Organisation for Economic Co-operation and Development, 2011).

Employment status: It denotes whether the surveyed sample is employed or not (including unemployed or retired). Many studies have found that retirement is related to overall and non-work daily vehicle travel changes (Berg et al., 2014; D. Ding et al., 2014; Hjorthol et al., 2010; Siren & Haustein, 2016).

Living arrangement: A dummy variable was included to denote whether the respondent lives alone. The household member size was also included as a variable. Based on previous literature, those who live alone have more difficulties in daily travel and tend to have fewer vehicle trips (Rosenbloom & Herbel, 2009).

Residential built environment: Three built environment variables available in NHTS public data were included: (1) *Blok-group level population density.* The public NHTS includes a categorical variable denoting the residential density at the block group level for each home address. This categorical variable was used in descriptive analysis and transformed it into a continuous variable using every category's midpoint in the regression models. (2) *Metropolitan area size where the respondent lives.* NHTS also includes a variable indicating whether the respondent's home address is in a metropolitan area; if so, what size the metropolitan area is. (3) *Urban/rural indicator.* NHTS has an urban/rural indicator developed by Claritas (Federal Highway Administration, 2010). Claritas categorizes each home address into one of the following categories: urban, suburban, secondary city, and town/rural areas based on the density of the grid cell where the home address is located in and the densities of the surrounding areas.

Other control variables included health conditions and whether the respondent was surveyed on a weekday as control variables. Health conditions are firmly associated with giving up driving among older adults (Adler & Rottunda, 2006; Taylor & Tripodes, 2001). NHTS in both years has asked two questions about health conditions and driving abilities: whether a person has medical conditions resulting in driving cessation and asking others for help. The answers to these two questions were included as dummy variables denoting health conditions related to driving abilities among sampled respondents. The designated travel days of the NHTS sampled individuals are either on weekdays or weekends. Previous studies have found that the survey day is firmly related to the travel pattern and should be included in the regression models (Blumenberg et al., 2016; McDonald, 2015; K. Wang & Akar, 2020).

2.3.2. Analytical Techniques

Several regression models on vehicle travel attributes were fitted as functions of the survey year, various attributes related to two generations, and the interactive term of these variables with the year. The demographic factors, socioeconomic attributes, employment status, living arrangement, and built environment attributes were included as independent variables. The coefficient of the survey year in regression models denotes, all else equal, whether boomers in 2017 travel more by vehicle than people of the same age in the silent generation in 2001. The interaction terms indicate controlling for all other factors of two generations, whether boomers in a subcategory, for example, living in the suburbs or being unemployed, travel less by vehicle in 2017, than those of the same age in 2001. The formula of regressions is as follows:

$$V = f(B_1 D + B_2 E + B_3 R + B_3 V + B_4 Y + B_5 I * Y + \varepsilon)$$

As the above formula shows, the vehicle travel outcome is a function of the demographic and socioeconomic attributes (D), employment status (E), residential location variables (R), other variables (V), generation indicator (Y), and the interaction term of a subset of the above factors (I) and the year (Y).[1] Vectors B_{1-5} denote the regression coefficients for the above variables. The error term is expressed in ε. While vectors B_{1-4} denote associations of these variables with travel outcomes for both generations, vector B_5 indicates how one factor is associated with the travel outcomes of the baby boomer generation and the silent generation differently. The year 2001 was set as a reference group. In this sense, the interaction term establishes whether vehicle travel is associated with one variable, e.g., living in the suburbs or income, differently in 2017 than in 2001. Three sets of models were performed for this study: three travel outcome variables for (a) all vehicle trips for those aged 56–71; (b) non-work trips for those aged 56–71; (3) non-work trips for those aged 65–71. Unlike young adults, non-work travel dominates older people's daily travel. However, delayed retirement of many in this age group might limit the time for their non-work travel. Those aged 65–71 were examined separately because their behavior has the most direct policy implications for older adults' transportation needs.

The negative binomial model was used to predict vehicle travel frequency as the outcome variable is the count variable.[2]A Tobit model was used to examine how factors associate with personal VMT, because the response variable is left-censored at zero. An ordinary linear squared model was used to fit the average vehicle trip distance. The VMT and average vehicle trip distance were transformed into the logarithm value plus one, as the distribution of original values has a long right tail. As for the model with average vehicle distance, only those who had vehicle trips were included in the model.

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[1] Two-way ANOVA tests were used to examine which factors should be included in regression models as interaction terms with the year (2001 versus 2017) (shown in Table A-2). A variable is included in a model if this the two-way ANOVA of this variable and the year on the outcome travel variable is statistically significant ($p<0.05$), which implies that there is 95% confidence to believe that the travel outcome variable is significantly different across different generations (proxied by year) for this variable.

[2] The Poisson regression results show that the distribution's variance is larger than the mean for all three models, which indicates that a negative binomial alternative is more appropriate than Poisson.

2.4. Results

2.4.1. Generational Changes in Daily Travel

Table A-2 (Appendix A) details generational changes of daily travel from 2001 to 2017 for those aged 56–71 using various indicators. As shown in the table, compared to VMT and non-work VMT among those in the silent generation, the vehicle travel distances of people of the same age in 2017 only slightly increased. However, baby boomers' travel frequency declined, and the travel distance increased compared to people of the same age in 2001.

How do the generational changes in demographic, socioeconomic attributes, and residential locations relate to the travel changes? As Table-A-3 in Appendix A displays, compared to people aged 56–71 in 2001, i.e., the silent generation, people in the same age group in 2017, i.e., baby boomers, were wealthier, more educated, had more diverse racial and ethnic compositions, and are more likely to stay in the labor force. Additionally, baby boomers tended to live in urban areas and secondary cities, denser places, and metropolitan areas. Nevertheless, those who lived in metropolitan areas tended to live in areas with smaller population sizes than people of the same age in 2001.

Table-A-4 in Appendix A details the changes in vehicle travel characteristics for different segments of the silent and baby boomer generations. The table confirms that personal VMT changes differ between those younger than 65 and those aged 65 and older. While those aged 56–64 in 2017 had significantly lower VMT (4 miles) than in 2001, the differences of those aged 65–71 in 2001 and 2017 are not statistically significant (0.2 miles).

Moreover, those with low incomes and less education underwent greater vehicle travel declines than people with higher income and educational attainment. For example, while those aged 56–71 with annual household incomes under $25,000 traveled 6 miles less per day on average from 2001 to 2017, those in the same age group whose household income was $100,000 and above had a consistent personal VMT of 41 miles in 2001 and 2017.

Women and non-Hispanic African Americans in the baby boomer generation aged 56–71 in 2017 had more personal VMT than in 2001. However, a consistent reduction in vehicle travel, across almost all social and demographic groups and residential locations, is found among those aged 56–71 in 2017 compared to those in 2001.

In terms of residential location, baby boomers in 2017 that lived in MSAs with populations 500,000 to 999,999 had more personal VMT than the silent generation living in the same type of area in 2001. Additionally, though people living in different types of places all experienced an increase in average vehicle travel distance from 2001 to 2017, the greatest increase by percentage occurred in urban areas and the densest populated places whose population density at the block level was more than 10,000 persons per square mile.

2.4.2. Regression Results

Regression results indicate the generational differences in vehicle travel using the dummy variable of survey year and interaction terms after averaging two generations' demographic, socioeconomic, and built environment characteristics in 2001 and 2017. Based on the research design, the coefficient of the year variable (2017 compared to 2001) shows whether a boomer's vehicle travel is significantly different compared to a person in 2001, keeping all other variables equal. By averaging other intergenerational variations, the interaction term indicates whether a subgroup in 2017 is significantly different from a group in 2001. For example, the negatively significant interaction of non-Hispanic African Americans and the year variable for vehicle travel implies that the baby boomer generation in 2017 had significantly fewer trips than the silent generation in 2001, keeping other variables constant.

The following text focuses on the results for two sets of models: regression results for logarithm term of VMT plus one, the car trips, and the logarithm term of average vehicle travel distance plus one among all people who made vehicle trips for: (a) all trips made by people aged 56–71 in 2001 and 2017 (Table 2.2); and (b) the same outcome variables for only non-work trips made by people aged 65–71 in 2001 and 2017 (Table 2.3). Regression results of the above three outcome variables for non-work trips only made by people aged 56–71 in 2001 and 2017 were presented in Table A-5 (Appendix A).

Controlling for the generational differences of boomers and the silent generation, boomers had less vehicle travel over time. Those aged 56–71 in 2017 (baby boomers) had 28.1% fewer personal VMT and 0.2 fewer vehicle trips than the silent generation in 2001, all else being equal (Table 2.2). These reductions may be attributed to the changes in the lifestyle of the two generations, such as more exposure to technologies among boomers.

However, keeping all other factors constant, personal VMT of those aged 65–71 increased by 8.3%, partly due to delayed retirement. The most dramatic difference between this group and people at the same age decades ago is their delayed retirement. Retirement creates more discretionary time for older adults and allows for more non-work travel. The increase in vehicle travel for this age group has two sources: more commuting trips by vehicle and more increased non-work travel among retirees in this age group than those in 2001 (Table 2.3).

Baby boomers who lived in the suburbs did not travel more than people at the same age in 2001. Controlling for other residential location attributes and socioeconomic factors, boomers who lived in the suburbs did not have more vehicle travel than the silent generation. As shown in Table 2.2, boomers aged 56–71 that lived in the suburbs in 2017 had nearly 10% fewer vehicle trips than their silent generation counterparts in 2001. Table A-5 (Appendix A) further confirms that this age group living in the suburbs and secondary cities also had fewer non-work personal VMT. However, urbanites in 2017 had greater vehicle travel distance than urban dwellers at the same age in 2001. Table 2.3 clarifies that urban boomers aged 65-71 had more non-work vehicle trips than urban residents at the same age in 2001.

Increases in vehicle travel did not occur with the interaction of the year and income variable. It hints that the relationship between income and vehicle travel has remained constant for the last two decades. The interaction term of educational attainment and year in Table 2.3 and Table A-5 (Appendix A) are also statistically significant. Keeping other variables constant, those aged 56–71 that had a high school education or higher had more personal VMT than the same group in 2001. College graduates also had more non-work VMT in 2017 than in 2001.

Women and racial and ethnic minorities vehicle travel increased from 2001 to 2017. Women aged 56–71 had 15.2% more VMT than women of the same age in 2001 (Table 2.2). Similarly, the VMT of non-Hispanic African Americans and Hispanics increased by 17.8% and 22.7% compared to 2001, respectively.

Table 2.2 Regression models on vehicle trips and vehicle miles traveled for all, and vehicle trip distance for those aged 56–71 who made vehicle trips in 2001 and 2017

Variable names	**Personal vehicle miles traveled per day Tobit**	**Vehicle trip negative binomial**	**Average vehicle trip distance log-linear**
Year: 2017	-0.281***	-0.194***	0.035
	(0.055)	(0.018)	(0.031)
Sex			
Reference: male			
Female	-0.182***	-0.032***	-0.097***
	(0.018)	(0.009)	(0.006)
Female × 2017	0.152***	0.056***	
	(0.021)	(0.010)	
Age			
Reference: <65			
>=65	-0.075***	0.024**	-0.067***
	(0.020)	(0.009)	(0.007)
>=65 × 2017	0.083***	0.012	
	(0.023)	(0.011)	
Race and ethnicity			
Reference: Non-Hispanic Whites			
Non-Hispanic African American	-0.216***	-0.120***	0.038**
	(0.050)	(0.025)	(0.013)
Other non-Hispanic races	-0.103*	-0.045*	0.034*
	(0.042)	(0.020)	(0.014)

Hispanic	-0.146**	-0.028	0.037*
	(0.054)	(0.026)	(0.015)
Non-Hispanic African American × 2017	0.178**	0.109***	
	(0.054)	(0.027)	
Other non-Hispanic races × 2017	0.054	-0.021	
	(0.048)	(0.023)	
Hispanic × 2017	0.227***	0.056*	
	(0.058)	(0.028)	
Household income			
Weighted household income (thousands U.S. dollars)	0.003***	0.001**	0.002***
	(0.001)	(0.0002)	(0.0001)
Weighted household income (thousands U.S. dollars) × 2017	-0.0005	-0.0002	
	(0.001)	(0.0002)	
Employment status			
Reference: employed			
Unemployed or retired	-0.048*	0.016+	-0.061***
	(0.019)	(0.009)	(0.012)
Unemployed or retired × 2017	-0.171***	0.004	-0.094***
	(0.022)	(0.011)	(0.014)
Maximum educational attainment			
Reference: lower than high school			
High school	0.193***	0.121***	0.009
	(0.033)	(0.012)	(0.022)
Associate or equivalent	0.263***	0.179***	0.013
	(0.037)	(0.012)	(0.025)
College and higher	0.146***	0.191***	-0.039
	(0.037)	(0.012)	(0.024)
High school × 2017	0.077+		0.049
	(0.046)		(0.032)
Associate or equivalent × 2017	0.107*		0.059+
	(0.049)		(0.033)
	0.176***		0.080*

College and higher × 2017	(0.049)		(0.032)
Household composition			
Living alone			
Reference: No			
Yes	-0.154***	-0.005	-0.085***
	(0.027)	(0.013)	(0.010)
Yes × 2017	0.006	0.037**	
	(0.028)	(0.013)	
Household size	0.013+	0.007+	0.009+
	(0.007)	(0.003)	(0.005)
Residential built environment			
Population density			
Population density of the block group (thousand persons/square mile)	-0.048***	-0.013***	-0.012***
	(0.001)	(0.001)	(0.001)
Population density of the block group (thousand persons/square mile) × 2017		-0.001	
		(0.001)	
Urban indicator			
Reference: small town and rural			
Secondary city	-0.197***	0.068***	-0.321***
	(0.026)	(0.012)	(0.010)
Suburban	-0.146***	0.053***	-0.280***
	(0.027)	(0.013)	(0.009)
Urban	-0.369***	-0.053*	-0.313***
	(0.043)	(0.024)	(0.016)
Secondary city × 2017		-0.041	0.009
		(0.029)	(0.015)
Suburban × 2017		-0.096**	-0.01
		(0.031)	(0.015)
Urban × 2017		-0.03	0.058*
		(0.044)	(0.027)

The population size of the Metropolitan Statistical Area (MSA) of the home address			
Reference: In an MSA of Less than 250,000			
Not in an MSA	-0.004	-0.019	0.046***
	(0.030)	(0.014)	(0.010)
In an MSA of 250,000 – 499,999	0.021	-0.022	0.068***
	(0.031)	(0.015)	(0.011)
In an MSA of 500,000 – 999,999	0.053	-0.027	0.086***
	(0.038)	(0.018)	(0.011)
In an MSA of 1,000,000 – 2,999,999	0.105**	-0.025	0.133***
	(0.036)	(0.017)	(0.011)
In an MSA of 3 million or more	0.125***	-0.055***	0.200***
	(0.032)	(0.015)	(0.010)
Not in a metropolitan area × 2017	0.032	0.024	
	(0.035)	(0.017)	
In an MSA of 250,000 – 499,999 × 2017	0.095*	0.042*	
	(0.037)	(0.017)	
In an MSA of 500,000 – 999,999 × 2017	0.084*	0.033+	
	(0.042)	(0.020)	
In an MSA of 1,000,000 – 2,999,999 × 2017	0.090*	0.021	
	(0.041)	(0.019)	
In an MSA of 3 million or more × 2017	0.083*	0.01	
	(0.036)	(0.017)	
Health			
Having health conditions resulting in giving up driving	-0.774***	-0.468***	0.016
	(0.044)	(0.025)	(0.033)
Having health conditions resulting in asking others for help	-0.266***	-0.092***	-0.100***
	(0.027)	(0.013)	(0.019)
Travel day			
Reference: weekend			
Weekday	0.031**	0.058***	-0.028***
	(0.011)	(0.005)	(0.007)
Constant	3.103***	1.308***	12.117***

	-0.047	-0.021	-0.485
Observations	79,946	79,946	75,198
R^2			0.028
Adjusted R^2			0.028
Log Likelihood	-130,964.20	-179,617.20	
AIC		359,320.30	

Notes: +p<0.1, ***p<0.05, **p<0.01,*p<0.001. Values in parentheses are the standard errors.

Table 2.3 Regression models on non-work vehicle trips and vehicle miles traveled for all, and non-work vehicle trip distance for those aged 65–71 who made vehicle trips in 2001 and 2017

Variable names	Personal vehicle miles traveled per day Tobit	Vehicle trip negative binomial	Average vehicle trip distance log-linear
Year: 2017	-0.549***	-0.289***	0.064***
	(0.084)	(0.029)	(0.013)
Sex			
Reference: male			
Female	-0.104**	-0.027+	-0.055***
	(0.035)	(0.016)	(0.010)
Female × 2017	0.131**	0.063***	
	(0.040)	(0.018)	
Race and ethnicity			
Reference: Non-Hispanic Whites			
Non-Hispanic African American	-0.276**	-0.058	0.017
	(0.094)	(0.047)	(0.022)
Other non-Hispanic races	-0.093	0.011	0.035
	(0.078)	(0.036)	(0.024)
Hispanic	-0.098	-0.002	0.028
	(0.103)	(0.048)	(0.025)
Non-Hispanic African American × 2017	0.270**	0.075	
	(0.101)	(0.050)	
Other non-Hispanic races × 2017	0.133	0.028	
	(0.112)	(0.053)	
Hispanic × 2017	0.227***	0.056*	
	(0.058)	(0.028)	

Household income			
Weighted household income (thousands U.S. dollars)	0.002***	0.0001	0.001***
	(0.000)	(0.000)	(0.000)
Weighted household income (thousands U.S. dollars) × 2017		0.0004	
		(0.000)	
Employment status			
Reference: employed			
Unemployed or retired	0.501***	0.211***	0.023*
	(0.039)	(0.018)	(0.012)
Unemployed or retired × 2017	0.266***	0.140***	
	(0.044)	(0.021)	
Maximum educational attainment			
Reference: lower than high school			
High school	0.158**	0.143***	0.024
	(0.058)	(0.020)	(0.025)
Associate or equivalent	0.237***	0.196***	0.018
	(0.066)	(0.020)	(0.025)
College and higher	0.094	0.204***	-0.008
	(0.063)	(0.020)	(0.025)
High school × 2017	0.123		
	(0.082)		
Associate or equivalent × 2017	0.113		
	(0.087)		
College and higher × 2017	0.256**		
	(0.084)		
Household composition			
Living alone			
Reference: No			
Yes	-0.189***	-0.021	-0.122***
	(0.027)	(0.023)	(0.017)
Yes×2017		0.035	
		(0.023)	
Household size	-0.033*	-0.005	-0.018+

	(0.015)	(0.007)	(0.009)
Residential built environment			
Population density			
Population density of the block group (thousand persons/square mile)	-0.045***	-0.014***	-0.011***
	(0.002)	(0.001)	(0.002)
Urban indicator			
Reference: rural areas and towns			
Secondary city	-0.205***	0.079***	-0.317***
	(0.026)	(0.021)	(0.016)
Suburb	-0.170***	0.074***	-0.254***
	(0.025)	(0.022)	(0.015)
Urban	-0.408***	-0.105**	-0.295***
	(0.043)	(0.037)	(0.026)
Secondary city × 2017		-0.008	
		(0.023)	
Suburban × 2017		-0.040+	-0.01
		(0.024)	(0.015)
Urban × 2017		0.085*	0.058*
		(0.037)	(0.027)
The population size of the Metropolitan Statistical Area (MSA) of the home address			
Reference: In an MSA of less than 250,000			
Not in an MSA	0.034	-0.008	0.060***
	(0.027)	(0.013)	(0.016)
In an MSA of 250,000 – 499,999	0.085**	0.006	0.070***
	(0.031)	(0.014)	(0.018)
In an MSA of 500,000 – 999,999	0.090**	0.003	0.055**
	(0.030)	(0.014)	(0.018)
In an MSA of 1,000,000 – 2,999,999	0.134***	-0.007	0.110***
	(0.031)	(0.014)	(0.018)
In an MSA of 3 million or more	0.138***	-0.030*	0.140***
	(0.028)	(0.013)	(0.017)
Health			
	-0.583***	-0.365***	-0.03

Having health conditions resulting in giving up driving	(0.077)	(0.039)	(0.049)
Having health conditions resulting in asking others for help	-0.217***	-0.104***	-0.062*
	(0.048)	(0.023)	(0.029)
Travel day			
Reference: weekend			
Weekday	-0.184***	0.019*	-0.100***
	(0.020)	(0.009)	(0.012)
Constant	2.645***	1.135***	2.046***
	(0.076)	(0.035)	(0.037)
Observations	32,847	32,847	29,232
R^2			0.051
Adjusted R^2			0.05
Log Likelihood	-57,188.17	-74,250.37	
AIC		148,570.70	

Notes: +p<0.1, ***p<0.05, **p<0.01,*p<0.001. Values in parentheses are the standard errors.

2.5 Conclusions

The giant number of baby boomers and the significant diversity among them will change the transportation policies for future older adults. While many policymakers and planners worry that baby boomers will drive more than people of the same age, analysis (controlling for socioeconomic and residential built environment factors) using the 2001 and 2017 NHTS, unearthed no evidence for this argument. Additionally, baby boomers who lived in the suburbs did not travel more than suburbanites in the early 2000s. This result shows the potential to nudge sustainable travel behavior among baby boomers. However, it should be noted that retirement is directly related to more non-work vehicle trips. Another crucial finding is that vehicle travel difficulties of older adults with low incomes and less education persisting over the past two decades, even boomers are healthier and wealthier than previous generations on average.

This study has two limitations regarding data and research design and calls for future research. First, the NHTS data is repeated cross-sectional data and cannot sort out the generation, age, and temporal effects. The sample recruiting differences across different survey years may also bias the results. Future research can better sort out the role of generation on older adults' travel if longitudinal data on older adults' travel outcomes are available. Second, the mechanisms of the travel behavior changes of the baby boomers compared to the silent generation is not clear in this chapter. For example, do low-income and less educated older adults travel less due to vehicle ownership difficulties? Did boomers' lower vehicle travel have anything to do with the age differences in technology usage? Future research should examine more about the reasons behind the travel behavior changes.

Chapter 3. *Aging in Place or Stuck in Place? An Examination of Zero-Vehicle Older American Households Living in Low-Density Areas*

3.1. Introduction

Vehicle dependence is nearly universal among U.S. residents, and older adults are no exception. Given the large amount of baby boomers, this age group has significant planning implications. Compared to older cohorts, today's older adults rely more heavily on vehicles in daily travel. For one thing, today's older adults are more willing to age in their own homes or at least remain in their communities (AARP, 2018; Joint Center for Housing Studies of Harvard University, 2019). For another thing, as those with medical conditions and living alone increases rapidly, those who has health and income difficulties in owning and maintaining their vehicles are also rising.

Federal and local transportation support for older adults in this country mainly include reduced fares for public transit, paratransit, and community van services (Rosenbloom, 2009). They have largely ignored the transportation needs of older adults who live in low-density suburbs and rural areas. Transportation policies and funding largely neglected the increased travel difficulties and costs for those who want to age in suburbs and other low-density areas and have had to temporarily or permanently give up their vehicles because of income or other constraints.

In this way, older adults who hope to *age in place*, which is defined as staying in their own homes or communities without changing their quality of life as they age, might be *stuck in place*. In this chapter, I define *stuck in place* as: at a point in time, a household headed by an older adult decided to reside in a low-density area without owning a car. Such a household has few, if any, alternative public transportation resources for their necessary travel.

Who are the older adults *stuck in place*? What are the implications for transportation planning for future older adults? This chapter aims to answer the questions by understanding the demographic and socioeconomic attributes of older adults having no cars but living in car-dependent areas. This examination fills the current gap in the literature on vehicle ownership and social outcomes and factors related to zero-vehicle households (Blumenberg, 2004; Blumenberg et al., 2020; Brown, 2017; Klein, 2020; Klein & Smart, 2017b) by offering a case for older adults. It also provides evidence for new policies that could offer additional financial or transportation support for older adults living in low-density areas.

3.2. Literature Review

In car-dependent areas, living without a vehicle, or an insufficient number of vehicles, adds to daily travel difficulties. It adversely influences people's daily access to employment, social, and recreational activity destinations. This section starts with the literature about vehicle ownership difficulties among socioeconomically disadvantaged groups, followed by a discussion on why older people, especially some segments among older people, are disadvantaged in vehicle ownership. This section ends with a summary of research gaps and how they motivate the current study.

3.2.1. The Role of Vehicles in Economic and Social Outcomes

Despite not focusing on older people, planning and transportation literature have documented the positive economic and social benefits of owning a car. Owning an automobile enables people to engage in economic, health, and social activities, and thus reduces poverty and social inequity. Building on national data in various Western countries, Morris et al. (2020) showed that lacking a private vehicle was associated with fewer out-of-home activities. When it comes to the relationship between owning a vehicle and employment outcomes, Bastiaanssen et al. (2020) has documented the relationship is positive based on a meta-analysis. Owning a vehicle facilitates low-income people searching jobs, getting to the destinations on time and maintaining jobs, and qualified for job opportunities which require driving (Blumenberg & Manville, 2004; Blumenberg

& Pierce, 2014; Cervero et al., 2002; Coren et al., 2022; Ong, 2002). In addition to job opportunities, owning a car can also increase people's choices in other non-work opportunities. For example, owning a car enables people to access to cheaper and healthier food more easily (Clifton, 2004; Páez et al., 2010), have timely healthcare visits and treatments (Arcury et al., 2005; Syed et al., 2013), and engage in more social activities (Özkazanç & Özdemir Sönmez, 2017). Having a vehicle is even more crucial for low-income women due to their greater need to balance work and life by trip chains more easily fulfilled by vehicles (Blumenberg, 2004).

The significance of vehicles in the economic and social lives has increased since 1990 as many people with lower incomes have moved to the suburbs (Ades et al., 2012; Covington, 2015; Hochstenbach & Musterd, 2018; Kneebone & Garr, 2010; Raphael & Stoll, 2010). In suburbs and rural areas, vehicle ownership is usually a necessity rather than by choice, which adds to residents' travel expenses. This phenomenon is referred to as *forced vehicle ownership* (Curl et al., 2018). Unlike those who are *car-free* and can take advantage of alternative transportation modes in urban areas, zero-car households living in suburban or rural areas, the so-called *car-less families*, often face the mismatch between vehicle needs and ownership (Brown, 2017). Based on the evidence in Australia, Delbosc & Currie (2012) highlighted that zero-vehicle and one-vehicle households living in areas with fewer transportation options had less social support in daily travel and more mobility restrictions in daily activities. In contrast, those who had one vehicle and lived in communities with more transportation alternatives did not feel any travel difficulties. Another study in Toronto, Canada noted that the increasing number of low-income people living in vehicle-dependent areas and the lack of vehicles among them had contributed to their lower activity participation (Allen & Farber, 2021).

3.2.2. Stuck in Place among Older People

Living in a car-dependent area adds to the older adults' daily travel burdens. Those who hope to stay in low-density areas should have the capability to own, maintain, and drive vehicles. A recent study (Schouten et al., 2022) observed that older adults who lived in dense urban areas or transit-rich areas tended to give up driving earlier in life. Another study found that successfully implementing smart growth strategies reduced older adults' dependence on vehicles (Bai et al., 2021).

Gerontology theories suggest that older adults need to move to denser and more accessible places to address their declined functional and physical mobility to achieve person-environment fit (Lawton, 1982; Lawton & Nahemow, 1973; Lawton & Simon, 1968). However, literature from different disciplines shows that vehicle ownership and relocation decisions might not go hand in hand over the life course. In this section, I focus on the factors relate to being *stuck in place* among older people.

Literature suggests that age is related to being *stuck in place*. Compared to younger people, older people tend to have less social support for vehicle travel and own fewer cars, even controlling for other factors. For example, a study in Ireland found that households headed by those aged 25–44 were more likely to own two vehicles than households headed by older adults (Caulfield, 2012). A study in Spain ascertained that households headed by those aged 65 and over had lower vehicle ownership than households headed by other age groups (Matas & Raymond, 2008). A study using the 1998–2003 German Socioeconomic Panel demonstrated that when a head of household's age was over 40, vehicle ownership increased more slowly as people aged and finally decreased with age (Prillwitz et al., 2006).

Older adults also tend to live in low-density areas at a greater rate than younger people. The U.S. suburbs are rapidly aging due to the increasing number of baby boomers living in the suburbs (Frey, 2006, 2007). In addition, today's older people aged 50 and over have lower migration rates over time, as the relocation rate declines with age (Frost, 2020; Joint Center for Housing Studies of Harvard University, 2019). That said, the number of older adults who age in suburban communities will keep increasing in the next decades.

Life stages are also related to being *stuck in place*. While certain life stages, such as living alone, and retirement, are related to living in households with fewer and zero vehicles, these life stages do not necessarily predict residential relocations. In transportation literature, the mobility biography theory holds that travel behavior will continue as routines unless some new circumstances, such as losing a partner, retirement, getting a new job, or relocation, happen (Lanzendorf, 2003). These life-cycle events may trigger new adaptions in daily travel and thus develop people's new travel habits (Rau & Manton, 2016; Scheiner & Holz-Rau, 2013; Schlich & Axhausen, 2003). This theory is later applied to understand vehicle ownership changes over the life course (Clark et al., 2016; Klein & Smart, 2019). Current studies have found reductions in income (Clark et al., 2016; Klein & Smart, 2017b; Nolan, 2010), living alone (Caulfield, 2012; Potoglou & Kanaroglou, 2008; Whelan, 2007), and retirement (Klein & Smart, 2019; Oakil et al., 2014) were related to declines in vehicle ownership.

However, life-cycle events may not trigger relocation to denser populated places as the theories suggest. As discussed above, today's older adults are less likely to move than previous generations. Some empirical studies have shown that those living in low-density suburbs might not relocate when the living environment is an obstacle to their daily travel (Granbom et al., 2019; Pope & Kang, 2010). Even if they choose to relocate, they might relocate to more affordable suburban areas rather than denser urban areas (Li et al., 2022). Other cultural, psychological, and social factors, such as place attachment and social capital in the community, discourage people from relocation (Golant, 2015a, 2015b; O'Bryant & Murray, 1987).

3.2.3. A Summary of Research Gaps

The above literature review shows at least three research gaps. First, despite a large number of studies on vehicle ownership and activity participation, few of them focus on older people. In gerontology and transportation studies, scholars tend to agree that deciding to stop driving, so-called "driving cessation", is negatively related to older people's independence, autonomy, and social participation (Adler & Rottunda, 2006; Chihuri et al., 2016; Curl et al., 2014). Due to the large number of baby boomers and how they contribute to the suburbanization of poverty, lacking a vehicle, including temporarily, can be another factor contributing to older people's travel difficulties.

Second and related to the first point, though subsidizing vehicles for low-income people are debatable as of the conflict between social equity and sustainability, current vehicle subsidy policies, which focus mainly on getting people to employment opportunities, naturally exclude older people, who are mostly out of the labor market. For the future transportation policy design for older people, one might ask: is age a contributing factor to be *stuck in place*? Or does age contribute to being *stuck in place* for socioeconomically disadvantaged groups, such as women living alone and low-income people? For example, female older adults might have more difficulties in vehicle travel than older men (Rosenbloom & Herbel, 2009). Will they also have higher possibility of being *stuck in place* than men when they age? Answering these questions would help advance social equity for transportation policies for older people.

Last but not least, the discussion on the mismatch between vehicle needs and ownership are recent in transportation and planning literature. The review suggest that older adults are more likely to experience a mismatch between vehicle needs and ownership when they retire or are widowed. Several U.S. and international studies found that car dependence in daily travel might not go hand in hand with living in low-density areas (Guerra, 2015; Li & Zhao, 2017; Shen et al., 2016; Smart & Klein, 2018a). However, current studies did not discuss the mismatch among older people. From the policy perspective, considering the large number of baby boomers and the diverse socioeconomic attributes of today's older adults, identifying people who are *stuck in place* and those who live in urban areas but have multiple cars can help policymakers reconsider social equity and sustainability issues in transportation policies for older people.

3.3. Setting the Context: Vehicle Ownership and Residential Locations of Older Americans

Figure 3.1 shows the vehicle ownership levels among people aged 55 and over in 2001, 2009, and 2017. Based on the definition of Blumenberg et al. (2020), I classify people into one of the three types of households: (a) zero-car households that have no cars; (b) car-deficit households that have less than one car per driver; and (c) full-equipped households that have at least one car per driver. The figure shows that older adults at older ages are also more likely to live in zero-car and car-deficit households. One in ten Americans aged 75 and older lived in zero-car households in 2017, while the percentages among those aged 55–64 and 65–74 were 7.3% and 7.8%, respectively.

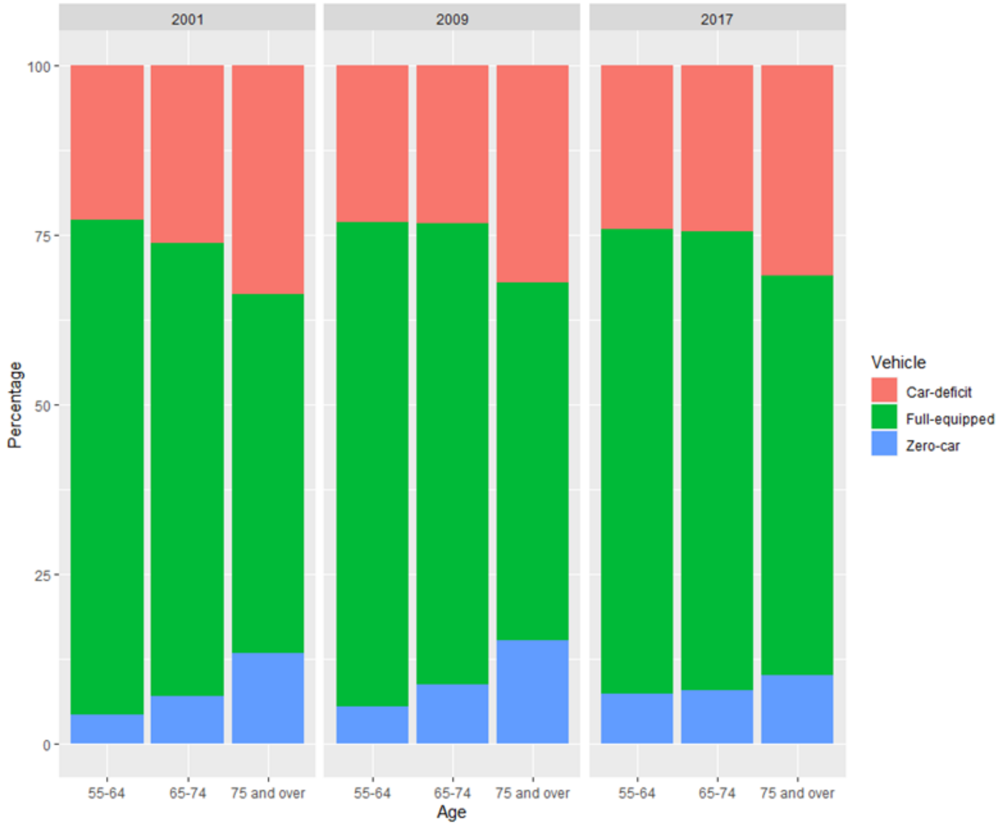

Figure 3.1 *Percentages of people aged 55 and over living in zero-car, car-deficit, and full-equipped households 2001, 2009, and 2017*
Data source: *National Household Travel Surveys 2001, 2009, and 2017.*
Notes: *All values in the table are weighted using personal weights.*

Table 3.1 further establishes that access to a car is firmly associated with daily travel. Table 3.1 also uncovers that those who lived in car-deficit and zero-car households had significantly lower personal miles traveled per day. Though people aged 75 and over living in car-deficit and full-equipped households had fewer vehicle trips than those aged 55–74, regardless of age, a person aged 55 and over living in zero-car households made more than one trip by a vehicle on the travel day in all three datasets (2001, 2009, and 2017). Unlike the travel pattern in younger groups, the number of vehicle trips for those aged 75 and older living in zero-car households slightly increased compared to that in 2001.

Table 3.1 Travel outcomes of people living in households with different vehicle ownership status by age 2001, 2009, and 2017

Year	Age group	Car ownership	Number of vehicle trips	Vehicle miles traveled	Personal miles traveled
2001	55–64	Zero-car	1.31	8.47	14.20
		Car-deficit	4.10	35.49	36.75
		Full-equipped	4.45	41.89	42.62
	65–74	Zero-car	1.48	12.88	18.14
		Car-deficit	4.16	28.96	29.85
		Full-equipped	4.53	35.10	35.85
	75 and over	Zero-car	1.35	9.50	13.75
		Car-deficit	3.63	22.81	23.80
		Full-equipped	4.06	27.84	28.77
2009	55–64	Zero-car	1.04	6.52	13.74
		Car-deficit	3.90	32.52	33.90
		Full-equipped	4.12	38.05	39.10
	65–74	Zero-car	1.03	5.13	10.68
		Car-deficit	3.86	28.06	28.99
		Full-equipped	4.28	34.13	34.81
	75 and over	Zero-car	1.23	6.95	10.72
		Car-deficit	3.50	23.01	23.88
		Full-equipped	3.87	26.33	26.75
2017	55–64	Zero-car	1.06	8.35	16.94
		Car-deficit	3.73	30.68	32.80
		Full-equipped	3.89	39.43	41.00
	65–74	Zero-car	1.05	6.22	13.48
		Car-deficit	3.56	29.09	30.95
		Full-equipped	4.06	36.95	38.13
	75 and over	Zero-car	1.42	12.08	17.48
		Car-deficit	3.31	23.06	23.93
		Full-equipped	3.82	30.66	31.71

Data source: National Household Travel Surveys 2001, 2009, and 2017.
Notes: All values in the table are weighted using personal weights.

In the meantime, people aged 55 and over living in suburban and rural areas have increased rapidly since 2000. As shown in Figure 3.2, as boomers aged, suburban populations have exploded since 2000, with suburbanites in 2018 aged 55–74 outnumbering those living in urban areas by a larger margin than in 2000.

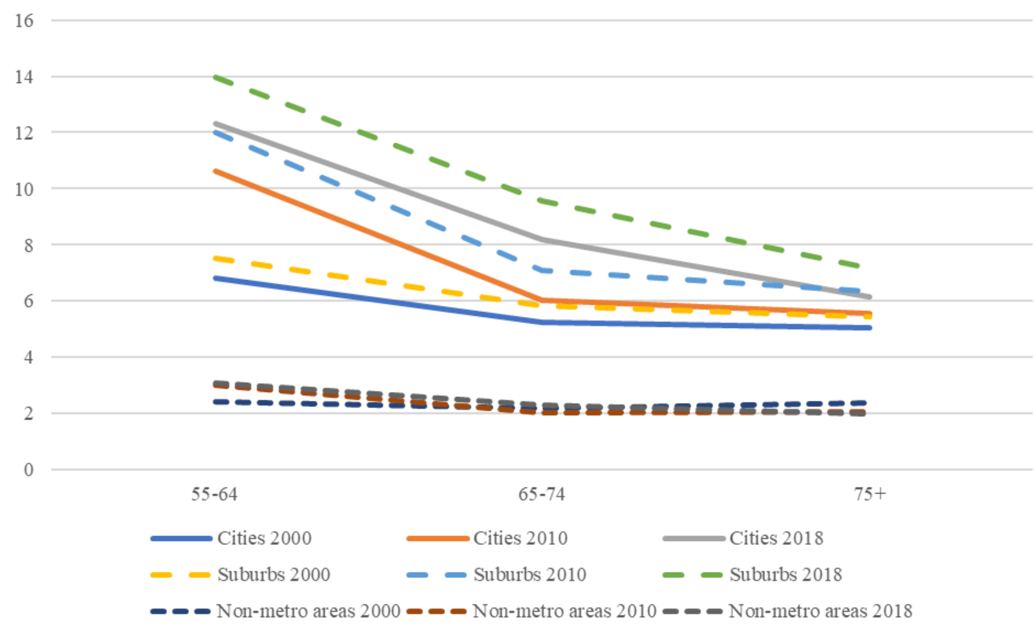

Figure 3.2 *Number of people aged 55–64, 65–74, and 75 and over living in cities, suburbs, and non-metro areas 2000–2018 (Unit: millions)*
Data source: *Decennial Census 2000 and 2010, American Community Survey 2014–2018*
Notes: *Cities are defined as census designated places (CDP) in Metropolitan Statistical Areas (MSAs) and New England city and town areas (NECTAs) delineated by the U.S. Office of Management and Budget (OMB). Suburbs are CDPs outside the cities in MSAs and NECTAs. Accordingly, all other places are non-metropolitan areas. Please note that the definitions of cities and suburbs are different from that in formal analysis using the NHTS data.*

The existing built environment of most U.S. neighborhoods is not age-friendly either. In an ideal scenario, people of older ages should live in more walkable neighborhoods with easier access to daily activity destinations to compensate for their decline in mobility. Unfortunately, this does not reflect the reality of where most older adults live. Table 3.2 presents the neighborhood-level built environment characteristics where 25%, 50%, and 75% of people aged 55–64, 65–74, and 75 and older lived. The table establishes that fewer than 25% of older adults lived in census tracts with more than 4,000 people per square mile. More than half of those aged 75 and over lived in census tracts without a single bus stop, and where one cannot get to any places via transit within 30 minutes. In contrast, those aged 55–64 lived in places with more extensive bus services. Also, a majority of older adults aged 65 and over lived in neighborhoods with below-average walkability.[3]

[3] In EPA's definition, places with a walkability index lower than 10.50 is considered as below the average level of walkability of the nation.

Table 3.2 The neighborhood-level built environment characteristics of older adults in the U.S.

	75%	**50%**	**25%**
Population density (thousand persons/square mile)			
55–64	0.23	1.5	4.1
65–74	0.2	1.4	3.7
75 and over	0.25	1.5	3.9
Transit accessibility (Number of jobs within a 30-min transit ride)			
55–64	0	132	5,442
65–74	0	2.1	4,600
75 and over	0	0	5,306
Walkability			
55–64	5.8	7.8	11.2
65–74	5.7	7.6	10.8
75 and over	6	7.9	11.2

Data source: Population density data comes from the 2015–2019 American Community Survey data. Transit accessibility comes from the Accessibility Observatory at the University of Minnesota (Owen and Murphy, 2018). Walkability data comes from Smart Location Dataset developed by the Environmental Protection Agency (Ramsey and Bell, 2014).

3.4. Research Design

3.4.1. Research Hypotheses

Based on the literature review and the U.S. context, I reach two hypotheses: First, *the tendency of being stuck in place increases with age.* As the literature review and the context shows, people at older ages are more likely to live in zero-vehicle households, however, they are not more likely to live in denser and more walkable neighborhoods. Controlling for other factors, if age itself is a contributing factor to be *stuck in place*, then federal and local governments should provide additional transportation and housing support for older people living in low-density areas, regardless of their income, race, and other characteristics.

Second, *several segments of older people, for example, women living alone and low-income older people, might be more likely to be stuck in place, and the risk of being stuck in place among them increases with age.* As the literature review shows, while some older people, such as those who live alone, low-income older people, and retirees, have more difficulties owning and maintaining vehicles, they may not be able to afford to move to dense urban cores. Additionally, for these people, their likelihood to be *stuck in place* might increase as they age, when they experience greater declines in health and functional mobility. As they age, they may also be less likely to relocate. If this is the case, transportation and housing policies should identify such disadvantaged people who are more likely to be *stuck in place*, and factor age in the support for people at certain life stages.

3.4.2. Data Sources and Measurements

To test the hypotheses, I draw the data from the NHTS 2017 to examine the vehicle ownership and residential location choices for households headed by 55 and over. As residential location and vehicle ownership are household-level decisions, the household rather than the individual is the unit of analysis. Only those whose household size is not larger than 5 were selected to rule out the influence of large households on vehicle ownership. Of 82,112 households headed by those aged 55 and over in the survey, 99.3% of households had members at five or fewer. I also deleted the observations with missing data on income. The final sample size is 74,063. As older people living alone and not living alone have considerations in vehicle ownership and residential locations, I separately analyzed the 27,675 households living alone and another 46,388 living with others. Table A-1 in Appendix B shows the descriptive statistics of final samples.

The outcome variable of models is a combined decision of residential location and vehicle ownership level, for example, living in an urban area and without a vehicle. I measure the categories of residential locations using the urban indicator in NHTS. The urban indicator variable classifies the block groups in the U.S. into five categories: urban areas, suburbs, secondary cities, towns, and rural areas based on the density of this block group and the population densities of surrounding areas (Federal Highway Administration 2010). As the rural areas and towns had lower densities than other categories and the number of zero-vehicle households in these two areas is relatively small, I combined these two categories in the analysis. Appendix B presents the differences in density and travel characteristics of these categories. As for the vehicle ownership, while I included two vehicle ownership levels (having no car and having at least one car) for samples who lived alone, I specify three levels (having no car, one car, two and more cars) for those living with others to distinguish households with multiple cars from those with only one car. Based on the past studies, I include demographic and socioeconomic factors related to vehicle ownership and residential location choices of older Americans. In models for households living alone and not, the following variables are used as predictors: race and ethnicity of the head, household income, and employment status. As African American- and Hispanic-headed households are more likely to own zero or fewer cars (Blumenberg et al., 2020; Brown, 2017), I included two dummy variables: whether the household head is African American, and whether the head is Hispanic. As for household income, I include the logarithm form of the annual household income for those living alone. For those whose household size was between 2 and 5, I included the logarithm form of the annual household income weighted by the household size (divided by the square root of the household size) (Organisation for Economic Co-operation and Development, 2011). Since retirement might be a factor related to vehicle ownership and residential location, I included a dummy variable indicating whether the household head and the partner (if any) were unemployed (including temporarily leaving jobs or losing jobs, or being retired).

As those who live alone and do not have different considerations in vehicle ownership and residential location decisions, I consider specific factors in these two models. In the models for those who lived alone, I include the sex of the household head. In the models for those who lived with others, I include four other variables to examine the impact of household type and vehicle ownership. These variables include the marital status denoting whether the head is living with his/her partner, spouse, or others; a dummy variable denoting whether a household had more than two drivers; and whether the household head lives with children under 16 and above 16. For those living with children under 16 and younger, the householder may be more likely to keep their vehicles to drive the school-aged children to the daycare or school (Fan, 2017; McDonald & Aalborg, 2009). Living with a child older than 16 is a proxy of living with a dependent adult. Literature on young adults' daily travel indicates that young adults' delayed formation of households and staying in their parents' homes is a reason for their declined vehicle ownership and travel (Blumenberg et al., 2016; Klein & Smart, 2017a; McDonald, 2015). To reduce the calculation burden, I only included the variables denoting marital status and household structure as vehicle ownership variables rather than residential location variables.

3.4.3. Analytical Techniques

As discussed before, land use and vehicle decision are not independent decisions among older adults. Many factors commonly related to these decisions, including residential and travel preferences, life expectancy, and family wealth, which are not observed or readily measurable in the above studies. For example, those who have retired or are currently unmarried may still live in the suburbs, but experience vehicle declines or no-vehicle life. Their choice might be due to home attachment or the costs to relocate. In this study, I followed Guerra (2015) to fit several mixed logit models to account for the unobserved correlations of the residential location and vehicle ownership decisions. Technical Appendix C details the model considerations and specifications. I separately fitted the joint decisions of residential location and vehicle ownership for those who lived alone and did not. To examine the role of age in different segments' decisions in the second hypothesis, I further fitted six mixed logit models for those living alone and not living alone and are aged 55-64, 65-74, and 75 and older, respectively.

3.5 Results

In this section, I begin with an overview of the percentage of older households who were *stuck in place*, and how their socioeconomic attributes differed from those who were not. Then, I present the regression results to test the two hypotheses. They suggest which social groups are more likely to be *stuck in place*, and whether age is a contributing factor to be *stuck in place*.

3.5.1. Descriptive Analysis

As Table A-1 in Appendix B shows, for households headed by those who lived alone, 11% had zero cars, while 8% lived in non-urban areas. Zero-car households were less common among those who did not live alone, with only 1% living in non-urban areas having no cars. However, around 12% of household samples among those who did not live alone lived in non-urban areas with only one car, taking up around 80% of households with only one car. Table 3.3 further establishes that among those who lived alone, those who were *stuck in place* tended to be people of color, women, retirees, and low-income earners compared to those who were not.

Table 3.3 A comparison of socioeconomic attributes of households who were stuck in place versus who were not (living alone only)

	Stuck in Place (n=2,232)	Not stuck in place (n=25,443)
Average age	71.0	69.5
Sex		
Male	36.3%	31.2%
Female	63.7%	68.9%
Race		
African Americans	23.3%	8.5%
Not African Americans	76.7%	91.5%
Hispanic origin		
Yes	6.0%	4.3%
No	94.0%	95.7%
Annual household income (thousand dollars)	17.9	44.4
Employment status		
Employed	8.8%	32.8%
Not employed	91.2%	67.2%

3.5.2. Regression Results

Table 3.4 summarizes regression results for the regression on people of all ages (Table A-3 in Appendix B). Positive signs (positive values in the regression tables) imply a higher possibility of occurring than having no vehicle or living in urban areas, while negative signs (negative values in regression tables) mean a lower possibility of happening than the reference group. For example, in Table 3.4, the coefficient of having at least one car is positive for heads of households aged 75 and older living alone, implying that households headed by those aged 75 and older were more likely to own cars than those headed by ones aged 55–64, all else being equal.

Age is not Related to Being Stuck in Place

The result summary in Table 3.4 does not support the first hypothesis. All else being equal, age is not related to living in a low-density area without cars. Households headed by those aged 65–74 and 75 and older were more likely to have one car than those aged 55–64 who lived alone. For those who did not live alone, being older does not suggest a lower probability of living in a multiple-vehicle household. Moreover, households headed by those aged 65–74 were more likely to live in urban areas than those aged 55–64 if they lived alone. In contrast, those aged 75 and older preferred suburban living to urban life compared to those aged 55–64.

Retirees, Low-income People, and Women Living Alone are More Likely to be Stuck in Place

Consistent with the second hypothesis, retirees, women who live alone, and low-income older people have higher possibility of being *stuck in place*. Table 3.4 underscores that no matter if the household head lived alone or not, all else being equal, the retired or unemployed status of the household head and their partner, if any, predicts a lower possibility of owning cars, and a higher probability of living in non-urban areas. Similarly, a higher annual income is associated with higher possibilities of living in urban areas and owning vehicles, which imply the low-income older people are more likely to be *stuck in place*. Though retirement may reduce vehicle ownership needs, non-urban areas in the U.S. are far from car-free. Not having a car in a low-density location still produces travel difficulties for retirees. The results also show that low-income people, as the suburbanization of poverty, are more likely to live in low-density areas, perhaps more affordable than urban cores, but were more likely to live in zero-vehicle households.

Age Adds to the Possibility of being Stuck in Place for Some Segments

Results also partly support the second part of the latter hypothesis: Age is related to being *stuck in place* among some segments of older adults. Table A-4 and A-5 in Appendix B show the model results for households headed by those who lived alone and those who did not, for ages 55–64, 65–74, and 75 and older, respectively. However, the magnitudes of models for segments are not comparable to each other. For the limited space, I only demonstrate the results for those living alone (Table A-4) here.

While age adds to the possibility of being *stuck in place* for retirees and women living alone, it does not for low-income older people. As displayed in Table A-4, women aged 75 and older who lived alone tended to live in the suburbs and had no cars. However, the gender disparity in vehicle ownership and suburban living is not prevalent among those who lived alone and aged 74 and younger. While this pattern is similar among retirees, it does not hold for low-income people. The relationship between income and living patterns and vehicle ownership decisions are consistent with results in Table 3.4.

Disproportional Travel Difficulties among Other Disadvantaged Older People

Table 3.4 illustrates that Hispanic-headed and African American-headed households have lower possibility of owning at least one vehicle, though they were more likely to live in urban areas. As living in urban areas becomes increasingly unaffordable for low-income people, policymakers should understand these people's needs and obstacles in using transportation services and provide transportation alternatives for them to travel around.

Table A-4 in Appendix B further shows the disproportional travel difficulties among households headed by African Americans aged 65 and over compared to non-African Americans of the same age. This is because while households headed by African Americans aged 65–74 and 75 and older who lived alone tended to live in zero-vehicle households, they did not have higher possibilities to live in urban areas.

As the boomers and the young adults are increasing fast and becoming more diverse, vehicle ownership difficulties also extend to some near older adults. Table A-5 in Appendix B further uncovers that people aged 55–64 tended to live in zero-car households if they lived with children above 16. However, this pattern does not hold if the head of household was aged 65 and over.

Table 3.4 Predicted probability on residential location and vehicle ownership for households aged 55 and older living alone and living with others

	Householders living alone				Households not living alone				
	Residential location (Reference: urban areas)			Vehicle ownership (Reference: having no cars)	Residential location (Reference: urban areas)			Vehicle ownership (Reference: having no cars)	
	Suburbs	Secondary cities	Towns and rural areas	Having at least one car	Suburbs	Secondary cities	Towns and rural areas	Having one car	Having at least two cars
Age (Reference: 55-64)									
65-74	-	-	-	+			-		
75 and older	+			+	+			+	
Sex (Reference: Male)									
Female	+		-	-	NA				
Race (Reference: Not African Americans)									
African Americans	-	-	-	-			-	-	-
Hispanic origin (Reference:No)									
Yes	-	-	-	-	-	-	-		-
Household income									
Income (thousand dollars)	-	-	-	+	NA				
Income weighted by household size (thousand dollars)	NA				+	-	-	+	+
Employment status (Reference: at least one member (head or partner) was employed)									
Not employed	+		+	-	+	+	+	-	-
Marital status (Reference: Unmarried)									
Married	NA							+	+
Having at least two drivers at home (Reference: No)									
Yes	NA							+	+
Household structure									
Living with children under 16 (Reference: No)									
Yes	NA								
Living with children over 16 (Reference: No)									
Yes	NA							-	-

Notes: Only the coefficients that are statistically significant at the 0.05 level were presented in the table. Please refer to the Endnote II for why some variables were missed for the model on households not living alone.

3.6. Conclusions

As boomers age, the number of older adults in the U.S. are growing fast, with more people living in the car-dependent suburbs and rural areas. This study demonstrates that all else being equal, age itself is not a contributing factor to the possibility of living in non-urban areas and living without a vehicle. However, retirement, lower income, and being a woman and living alone all predicts such pattern-*stuck in place*.

The limitations of the data and the study at least raises two directions for future research. First, results show which social groups among older people are more likely to be *stuck in place*. However, the data can hardly provide evidence on the health and social implications of being *stuck in place*. The data also cannot answer how the risk of being *stuck in place* change over the life course. Such examinations require the longitudinal social and health surveys. Second, the built environment variables of this study lack many relevant variables, such as transit accessibility and walkability. When data are available at the local or national level, future research can further investigate how neighborhood-level built environment variables influence older adults' travel and residential locations, and the relative importance of these variables.

Chapter 4. *The Relationship Between Information Communication Technology Usage and Travel Behavior among Older People*

4.1. Introduction

In the last two decades, modern technologies have deeply influenced older adults' activity patterns and time allocation. For example, according to a report, the share of U.S. residents who have access to the Internet has climbed from 11% in 2000 to 67% in 2016. Additionally, in 2016, more than 40% of people aged 65 and over had smartphones, nearly four times the rate of that in 2011(Pew Research Center, 2017).

In the digital age, all types of ICT, such as online shopping, telecommuting, and social media, have the potential to reduce older adults' daily travel difficulties. These technologies might mitigate older adults' physical and geographical obstacles in daily life (Dal Fiore et al., 2014; Hill et al., 2015). It also reduces travel costs for older adults, especially those who need to travel by personal vehicle (Dal Fiore et al., 2014). Golant (2019) further states that ICT is promising in helping to mitigate the transportation difficulties for older adults who live in the suburbs and rural areas.

Despite the great potential of ICT in mitigating transportation disadvantages among older adults, an age-based digital divide exists among older adults. As the literature review suggests, older adults experience more difficulties accessing, accepting, and using various technological tools, while older adults with low incomes and lesser education suffer even more from the digital divide (Bucur et al., 1999; Czaja et al., 2006; Haight et al., 2014; Van Deursen & Helsper, 2015; Wright & Hill, 2009).

Those who suffer from the digital divide might also have additional transportation challenges. Does ICT reduce travel difficulties among older adults? If so, for whom and which activities? This examination provides evidence for transportation planners and urban planners to use technological tools to advance social equity. However, existing studies examining the relationship between ICT and travel behavior for older adults remain rare. This chapter aims to understand the relationship between ICT and travel behavior for different purposes among older adults.

4.2. Literature Review

Despite some evidence on how the relationship between ICT usage and daily travel for older adults might differ from young people, as well as the heterogeneity of the relationships among different older adult subgroups, none of the past studies have specifically examined the relationship between ICT and travel among older adults. Numerous studies have focused on overall ICT usage's impact on daily travel (Kong et al., 2020; Kroesen & Handy, 2015; Le Vine et al., 2016; Srinivasan & Reddy Athuru, 2004; D. Wang & Law, 2007). Many others have highlighted the role of specific types of technology, particularly telecommuting (He & Hu, 2015; Henderson & Mokhtarian, 1996; Zhu, 2012; Zhu et al., 2018) and online shopping (Cao, 2012; Cao et al., 2012; Farag et al., 2006, 2007; Zhou & Wang, 2014) on the offline equivalents (commuting and shopping trips, respectively). This literature first reviews the evidence on the relationship between ICT and travel behavior for different purposes, it then summarizes factors related to ICT and technology usage.

4.2.1. Evidence on the Relationship Between ICT and Travel Behavior

At the individual level, ICT and travel have four possible, but not purely exclusive relationships (Mokhtarian et al., 2006; Mokhtarian & Salomon, 2002; Salomon, 1986): (a) *substitution*: specific telecommunication tools replace out-of-home travel alternatives, e.g., e-banking; (b) *complementarity*: some ICT usage may trigger or generate new out-of-home activities because it frees up time for travel. It may also facilitate out-of-home travel; (c) *modification*: the use of ICT may help change a trip; and (d) *neutrality*: the use of ICT may not change out-of-home activities, e.g., sending an email.

Current studies show mixed results in regards to overall ICT usage and travel behavior. While some studies found that smartphone applications and Internet use complemented daily travel

(Kroesen & Handy, 2015; Le Vine et al., 2016; Srinivasan & Reddy Athuru, 2004; D. Wang & Law, 2007), some other studies claimed no significant relationship between ICT use and daily travel (Kong et al., 2020), or a slightly stronger substitutional effect (Konrad & Wittowsky, 2018). ICT reveals its complex interactions with activities in different ways. Reichman (1976) classifies daily activities into three types: subsistence (work and work-related), maintenance (shopping, medical, banking), and discretionary or leisure (social and leisure activities). While the technological alternative, e.g., online shopping, may substitute travel of the same category, in-store shopping, it may also change people's daily time allocation and travel patterns in other types of activities. In a recent article, Ettema (2018) summarized different types of technology based on its relationships with daily travel. Travel planning applications may generate new travel or facilitate travel, while other applications, e.g., shopping and banks, may substitute out-of-home travel. Games or entertainment tools are not related to travel and do not take up time for out-of-home activities. In the following sections, I focus on the literature of ICT's impact on travel for four purposes: telecommuting, e-shopping, social activities, and ride-hailing services.

Telecommuting

Most studies, especially more recent ones, agree that telecommuting does not help reduce daily travel. Since the late 1980s, the United States and other Western countries have started to consider the effectiveness of telecommuting in reducing commuting-related congestion and emissions. Early works using pilot before-after studies in some states of the U.S., primarily Washington and California, concluded that telecommuting reduced vehicle miles traveled (Henderson & Mokhtarian, 1996; Koenig et al., 1996; Pendyala et al., 1991). However, later studies have found the opposite conclusion (Asgari et al., 2016; Gould & Golob, 1997; He & Hu, 2015; S.-N. Kim, 2016, 2017; Zhu, 2012). It should be noted that several other studies have found negative relationships between telecommuting and overall trip frequency (Bieser et al., 2021; Elldér, 2020; Ozbilen et al., 2021). A recent study further explained that while telecommuters increased their active travel and use of public transit, they also demonstrated more vehicle travel than non-telecommuters (Chakrabarti, 2018).

E-Shopping

Another area of research focuses on the relationship between online shopping and in-store shopping. While some studies found that online shopping substituted for in-store shopping (Ferrell, 2004; Shi et al., 2019; Weltevreden & Rotem-Mindali, 2009), a lot more evidence documented that online shopping had a complementary effect on in-store shopping (Cao, 2012; Cao et al., 2010, 2012; Y. Ding & Lu, 2017; Etminani-Ghasrodashti & Hamidi, 2020; Farag et al., 2006, 2007; R. J. Lee et al., 2017; Zhou & Wang, 2014). Nevertheless, Zhou and Wang (2014) revealed that the relationship between online and in-store shopping was asymmetric: while those who e-shopped more made more shopping trips, those who made more shopping trips shopped online less.

However, modeling the online-offline equivalents might overlook the substitution effect of online activities. Cao (2009) argued that people who e-shopped more had less discretionary time to do other activities. However, this effect is overlooked in most e-shopping and travel literature. Similarly, Ding and Lu (2017) found that while online shopping induced more shopping trips, it took time from other activities, thus replacing other traditional leisure and social activities.

Social Activities

To my knowledge, only one study (Delbosc & Mokhtarian, 2018) has specifically examined the relationship between telecommunication usage, e.g., social media, email, and telephone, and face-to-face communications. The study found that increased telecommunication use was related to more, not less, face-to-face connections. However, this study did not examine how telecommunication use related to activities other than face-to-face communications.

Ride-Hailing

The relationship between ride-hailing application usage and travel behavior is inconclusive. A national examination in the U.S. (Kong et al., 2020) found that ICT strongly predicted ride-hailing usage, but not the usage frequency. Even so, some studies based on city-level travel data have found that ride-hailing usage has enabled people, especially those without vehicles, to conduct non-work trips (Brown, 2019; Young & Farber, 2019).

4.2.2. Factors Related to ICT and Travel Behavior

Despite the different ICT usage patterns of older and younger people, only a few studies have examined the role of age and life stage on the relationship between ICT and travel behavior. Many online shopping studies have shown that retirees and older people had fewer online shopping experiences (Cao et al., 2010; Etminani-Ghasrodashti & Hamidi, 2020; Farag et al., 2007; Zhou & Wang, 2014), which makes the substitution effect of online shopping for in-store shopping weaker for older adults. Delbosc and Mokhtarian (2018) found that older people used social media applications less frequently to facilitate daily social activities. Their results highlighted that while email significantly affected face-to-face communication for the 50–69 age group, it was inconsequential for those aged 70 and over. Also, social media was shown to facilitate face-to-face communication for younger adults. Some studies also noted that older people used ride-hailing services less than younger people (Alemi et al., 2018; Gehrke et al., 2019; Rayle et al., 2016), suggesting that ride-hailing apps might have a weaker effect on daily travel for older adults.

In addition to age, studies found that the relationship between ICT and travel behavior varied across different social groups based on gender, income, and location. Women and men may have different travel patterns in the digital age due to women's heavier responsibilities at home and more temporal-geographical constraints in daily travel. Le Vine et al. (2016) found that while Internet use and vehicle travel were significantly correlated for most age and gender combinations, they had insignificant relationships among women aged 45 and over. Another study described how online maintenance activities supplemented men's maintenance travel while substituting women's travel. However, online leisure activities reduced men's daily leisure travel but increased women's (Ren & Kwan, 2009).

ICT can theoretically reduce daily travel challenges for those with more burdens and difficulties in daily travel. Nevertheless, empirical studies have demonstrated that those with low incomes, residents in low-density areas, and racial minorities had lower technology use and traveled less. He and Hu (2015) found that telecommuters with low incomes generated fewer vehicle trips. Similarly, income was positively related to online shopping frequency (Cao, 2012). Several researchers have discovered that people with low incomes and low education had fewer in-store shopping trips (Cao, 2009a; Cao et al., 2010; Y. Ding & Lu, 2017; Etminani-Ghasrodashti & Hamidi, 2020; Ozbilen et al., 2021; Zhou & Wang, 2014). People who lived in denser populated places, especially urban areas, had more online shopping services (Maat & Konings, 2018; Shi et al., 2019; Zhou & Wang, 2014) and more ride-hailing usage (Jiao & Wang, 2021; Shirgaokar et al., 2021), while in some remote areas, the role of e-commerce on daily trips was at best marginal (Calderwood & Freathy, 2014). Sikder (2019)found that African Americans used ride-hailing services less than other races.

4.2.3. Research Gaps

The above review reveals at least three research gaps in the current scholarship on the relationship between ICT usage and travel behavior among older adults. Most importantly, no prior study has empirically addressed the relationship between ICT usage and travel behavior among older adults. Second, current studies on the relationship between ICT and travel for specific purposes mainly concentrated on teleworking and online shopping. ICT usage for other activities, such as social purposes and healthcare, was largely overlooked. A more holistic understanding of the relationship between ICT and travel for various activities among older adults will aid planners and other practitioners better organize spaces in communities and utilize ICT tools to advance older adults' participation in daily routines. Third, none of the previous studies examined the factors related to travel behavior and ICT usage among older adults. Understanding the relevant factors could help scholars and policymakers to identify older adults who suffer from travel difficulties and difficulties in using technology simultaneously.

4.3. Research Questions and Hypotheses

The focal questions for this chapter are: Does ICT increase the daily travel for older adults? If so, for whom and which activities? Three hypotheses guide this chapter.

Hypothesis 1. *All else being equal, the relationship between ICT and travel among older adults is insignificant or positive.*

The literature review clarifies that ICT is less influential in older adults' lives than younger people. Many studies have shown the positive relationship between ICT and daily travel overall. That said, people who use ICT more also travel more. Therefore, due to the generational digital divide and with less exposure to ICT, the relationship between ICT and travel behavior might be weaker among people at older ages. Thus, the relationship between ICT and travel among older adults might be positive or insignificant.

Hypothesis 2. *Older adults who have travel difficulties, e.g., those with low incomes, might also have more challenges using ICT.*

The literature review further establishes that some factors predict less out-of-home activities for some purposes and their online equivalents. For example, some studies have found that those with low incomes and less education tend to shop less in stores and online (Cao, 2012; Zhou & Wang, 2014). These constraints in online and offline activities may also apply to older adults and limit their daily travel and online activities.

Hypothesis 3. *Some specific types of ICT, however, might help reduce travel difficulties for older adults.*

The literature review details that older adults use ICT more for social and health activities. Current studies on ICT and travel mainly focus on working and shopping purposes, without much discussion on social and medical purposes. Theoretically, online services can replace in-person meetings if they can fulfill their functions or take time for face-to-face activities (Mokhtarian et al., 2006; Mokhtarian & Salomon, 2002). Compared to younger people, older adults who have income or health limitations accessing physical destinations might find the virtual options more attractive and participate in fewer out-of-home activities.

4.4. Research Design

In testing the hypotheses, I designed a survey targeting older adults in the U.S. and collected detailed technology usage and travel behavior data. The following sections detail the conceptual framework, survey design, and modeling strategies.

4.4.1. Conceptual Framework

Based on the literature and the hypotheses, I developed a conceptual framework to examine how ICT usage relates to daily vehicle travel overall and how different ICT activities correlate with their out-of-home equivalents (Figure 4.1). As shown in the figure, many demographic and socioeconomic factors, and the residential built environment attributes, are related to daily travel and ICT usage.

In addition to these factors, I also include some other control variables to estimate the relationship between ICT usage and daily travel. The literature review documents that the attitudes and perceptions towards the Internet are positively related to ICT usage. Thus, I control these variables in the conceptual model. In addition, many studies have shown that people might choose residential locations that meet their preferences for travel habits. Therefore, the estimates of the built environment variables as predictors can be biased without considering these individual preferences (Guan et al., 2020; Mokhtarian & Cao, 2008). For this reason, I also control for people's residential and travel attitudes and perceptions as control variables to account for the potential bias.

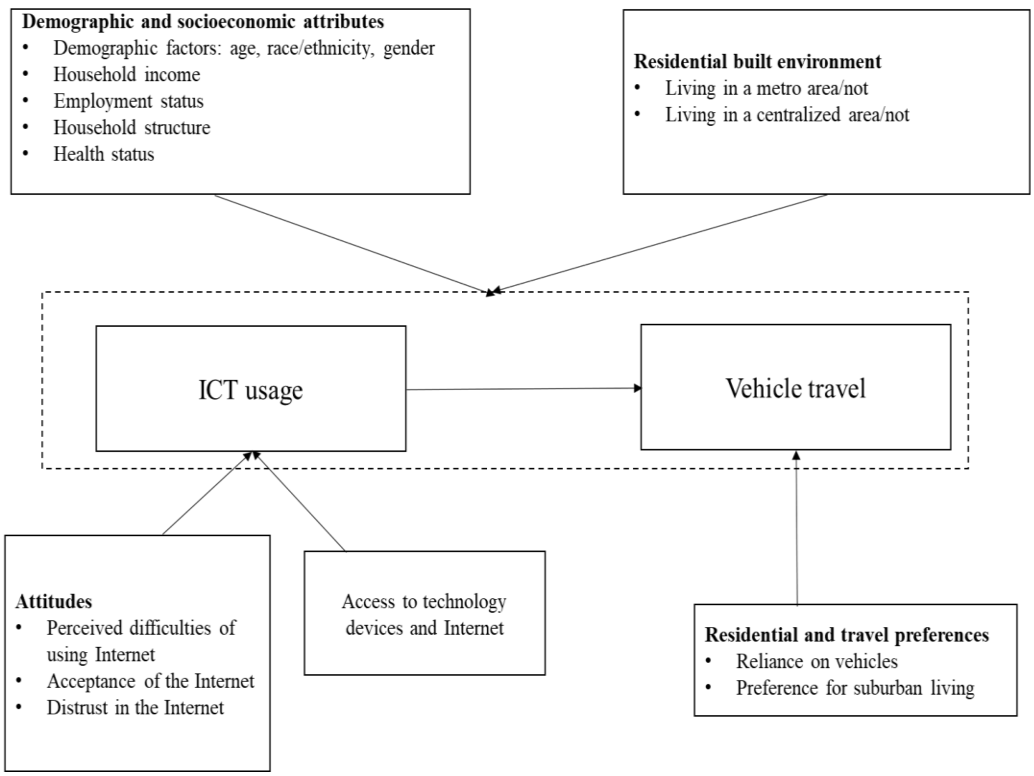

Figure 4.1 *Conceptual framework*

4.4.2. Survey Design and Data Collection

Based on the conceptual framework, I collected a national-level survey on older adults aged 60 and older to understand the relationship between ICT and travel among older adults and how their travel behavior and technology usage had changed during the pandemic. The survey was administrated by Qualtrics, a U.S.-based survey company. I collected the data from September to November 2021, after receiving approval from the Institutional Review Board of the University of Pennsylvania. As the study was conducted during the COVID-19 pandemic, when older adults' outdoor activities declined, I asked older adults to recall their out-of-home activities, technology usage, and other demographic and socioeconomic attributes before the pandemic outbreak, before February 2020, assessing the relationship between ICT and daily travel. I also collected data regarding their technology usage, travel behavior changes, and life-cycle events during the pandemic, February 2020 to February 2021, to further understand the changes during and after the pandemic and potential policy implications.

The survey adopts a quota sampling approach to ensure the samples are representative of the entire country's older population in terms of distributions of age, gender, race and ethnicity, income, educational attainment, and region of residence. In particular, I worked with the Qualtrics team to make sure that samples included enough numbers of older adults with low incomes, older adults aged 70 and older, and people of color. These subgroups are usually undersampled in national surveys, such as the 2017 NHTS. The reference data set for quotas came from the 2019 American Community Survey public-use microdata (PUMS). A pilot survey revealed that Qualtrics has difficulties recruiting Hispanics and older adults at older ages to answer the surveys. To increase the number of these samples, I added another version for caregivers of those aged 70 and over in the system. Quatrics invited qualified caregivers to fill out the survey for the person who received caregiving services. I also added a Spanish version to allow those who can only speak Spanish to accomplish the survey.

Table 4.1 lists the main variables in the survey and the comparisons with the 2019 PUMS and 2017 NHTS. As the table reveals, most of the characteristics are comparable to the 2019 PUMS. The survey also slightly oversampled people of color and older adults with lower incomes. In contrast, the 2019 NHTS oversampled younger older adults and older adults who have an annual family income higher than $100,000.

Similar to the 2017 NHTS, this survey also oversampled those with college degrees and undersampled those with less education. Since Qualtrics' survey partners recruit potential respondents solely online, the survey tends to rule out those who are not tech-savvy. Even so, the samples still include many people who did not have easy access to the digital world. Table 4.1 notes that 30% of respondents did not have stable access to the Internet.

Table 4.1 A summary of key variables in the survey and comparisons with the 2019 American Community Survey public-use microdata and the 2017 National Household Travel Survey

	The survey	**ACS 2019**	**NHTS 2017**
Age			
60–64	0.28	0.26	0.26
65–74	0.47	0.47	0.50
75 and over	0.25	0.27	0.23
Gender			
Male	0.45	0.46	0.46
Female	0.55	0.54	0.54
Race and ethnicity			
Non-Hispanic Whites	0.77	0.79	0.85
Non-Hispanic African Americans	0.11	0.08	0.06
Non-Hispanic all other races	0.04	0.06	0.05
Hispanics	0.07	0.07	0.04
Educational attainment			
High school and lower	0.30	0.41	0.28
Associate degree or some college	0.36	0.29	0.30
With college degree	0.35	0.31	0.41
Annual household income			
Under $25,000	0.33	0.18	0.19
$25,000–$49,999	0.33	0.22	0.25
$50,000–$99,999	0.11	0.31	0.33
Above $100,000	0.24	0.28	0.23
Employment status			
Still in the labor market	0.28	0.28	0.27
In the labor market but are not employed	0.02	0.01	0.73
Retired	0.70	0.71	
Household structure			
Living alone	0.34	0.29	0.25
Being married and living with the partner	0.46	0.46	0.75
All other cases	0.20	0.26	
Region			
Northeast	0.19	0.18	0.17
Midwest	0.22	0.22	0.15

West	0.23	0.22	0.26
South	0.37	0.38	0.42
Living in a metropolitan area			
Yes	0.83		
No	0.17		
Living in a centralized area			
Yes	0.87		
No	0.13		
Access to stable Internet			
Yes	0.70		
No	0.30		
Having difficulties walking and self-caring			
Yes	0.23	0.20	
No	0.77	0.80	
Having difficulties driving			
Yes	0.08		0.11
No	0.92		0.89

Notes: Values in the cells denote the shares of each category listed in the table. The sample of ACS and NHTS only consists of samples older than 60 and over. The sample size for ACS and NHTS are 940,618 and 102,518, respectively. None of the values are weighted.

Table 4.1 also highlights that most respondents lived in the central and metropolitan areas, though the regions where they lived are representative at the national level. This observation suggests that the survey oversampled those who lived in dense urban areas and undersampled those who lived in the suburbs, where most older adults today lived.

4.4.3 Measurements

Measuring Travel Behavior and Technology Usage

I asked the respondents to recall their daily travel frequency of out-of-home activities and 11 types of technology usage, as shown in Table 4.2. I elaborate on how I selected these activities in Appendix C.

I measure technology usage and out-of-home travel frequencies before the pandemic using Likert scales ranging from 1 to 5, with higher scores indicating higher frequencies. I asked the respondents to select one category of the following options as the frequency of using the technology applications: never, less than once a month, less than once a week but more than once a month, at least once a week but less than daily, and daily. Similarly, respondents were asked to select one of the categories as their frequency of out-of-home travel: never, less than once a month, less than once a week but more than once a month, once or twice per week, more than twice a week. I use the self-reported vehicle travel for different activities rather than the overall travel frequencies using all travel means.[4]

Table 4.2 Surveyed technology usage and out-of-home activities

Purpose	**Technology usage**	**Out-of-home activities**
Work-related	Having video/voice calls using FaceTime, Zoom, or other software for business/work reasons	Work or work-related
Shopping	Shopping online (not including meals)	Shop for food or durable goods (groceries, clothes, appliances, gas)
Dining out	Scheduling a restaurant or food delivery online	Buy meals (go out for a meal, snacks or drinks, carry-out)
Social activities	Using social media (e.g., Facebook, Instagram, and Twitter)	Visit family or friends

[4] Though I have asked respondents to report their travel using all travel modes and only with the vehicle, many respondents have underreported their overall travel frequency. Larger shares of respondents reported having conducted out-of-home activities for most purposes “more than twice a week” by vehicle than by all travel modes, which is counterintuitive. A possible reason for the seeming controversy is that recall surveys might underestimate travel trip frequencies, especially short and active trips (Stopher et al., 2007; Stopher & Greaves, 2007; Wolf, 2006). Though it is difficult to test whether the frequency of vehicle travel is more reliable than the overall frequency, I lean to believe that the frequency of overall travel frequency is less credible as people had more difficulty remembering their multimodal activities and tend to undercount their daily trips, especially for short ones made by foot or bicycle.

	Having video/voice calls using FaceTime, Zoom, or other software with friends/family	Religious or other community/volunteering activities
		Recreational activities (visit parks, movies, bars, museums)
Healthcare	Emailing or asking a question to a health professional online	Health care visit (medical, dental, therapy)
	Getting prescriptions for medicine online	
Buying services	Making an appointment online with a service provider (e.g., barbershop, pet care)	Buy services or other errands (e.g., dry cleaners, banking, service a car, pet care, haircut, going to the post office or library)
	Using an online bank or other transactional applications (e.g., PayPal and Venmo) to complete financial transactions	
Transportation technologies	Using Google Maps or other mapping/planning apps to check an address/traffic/routes or plan an out-of-home trip	All above activities + exercise (go for a jog, walk, walk the dog, go to the gym)
	Using smartphone apps to hail an Uber/Lyft/other on-demand transportation services	

Factors Related to Technology Usage and Travel Behavior Among Older Adults

Based on the conceptual framework (Figure 4.1), I also designed instruments to measure daily travel and technology usage factors among older adults. In the following paragraphs, I detail the measurements of these instruments.

Demographic and Socioeconomic Factors

I included age, race, ethnicity, gender, annual household income, employment status, household structure, and health status for this category of variables. For employment status, I included a dummy variable denoting whether or not the older adult retired. As for the household structure, I included a categorical variable denoting the living arrangement of the respondent using one of the following categories: living alone, living with the partner only, and all other cases. The annual household income was a categorical measure, with respondents selecting from 1 of 11 categories ranging from "less than $14,999" to "$200,000 and more."

Health Status

I included two dummy variables, i.e., difficulties driving and walking, denoting difficulties conducting out-of-home activities. Similarly to the 2017 NHTS (Federal Highway Administration, 2019), I asked the respondents to select whether they had medical conditions resulting in asking others for rides or giving up driving. Those who had at least one of the conditions were considered to have difficulties driving. Cognitive or physical disabilities preventing older adults from walking also interfere with daily mobility. I also asked whether the respondent had any problems climbing the stairs or self-caring, also asked in the 2019 ACS (U.S. Census Bureau, 2020). Those who had either problem were considered to have difficulties walking.

Attitudes and Perceptions Towards the Technology and the Internet

I measured the Internet and technology acceptance and trust based on the technology acceptance model using principal factor analysis (for details, please refer to Appendix C). As shown in Table A-3, four items have been reduced to two principal factors. Factor 1 captures older adults' acceptance of the virtual world indicated by the perception of the significance of the wireless Internet connection and the Internet as an information source. Factor 2 captures the level of distrust towards the Internet with two measurements: the level of preference for the real world over the virtual world; and the confidence in the security of online transactions using the credit card.

The usage of other technologies, including online shopping, e-health, and social media, is also related to respondents' preference for these technologies over their offline equivalents. Therefore, I also asked respondents to select "totally disagree" to "totally agree" (scored from 1-5) for statements about shopping trips, healthcare visits, and social media usage: "I prefer to shop in a store rather than online," "I prefer to see a doctor in person whenever I need medical help," and "social media (e.g., Facebook and Twitter) makes me feel less isolated." I include these variables as proxies of the perceptions of specific applications.

Access to the Technology

I measured the access to technology using a dummy variable, i.e., whether the respondent had a stable Internet connection. I also asked whether the respondent had a smartphone, a computer, or a tablet. However, these variables are highly correlated to the access to the Internet, so I removed them from the analysis.

Travel and Residential Preferences

Similar to measuring the attitudes related to technology usage, I also included several variables indicating individual preferences towards travel and residential choices (please refer to Appendix C for more details). As shown in Table A-4 in Appendix C, the first factor captures the dependence on a private vehicle. A higher score for this item implies the respondent's preference for living in suburban areas and depending on vehicles in their daily travel. Factors 2 and 3 capture two other different lifestyles. People who scored high on factor 2 are named *sustainable suburban lovers*, which indicates their preference for suburban lives with the willingness to take more sustainable alternative travel modes, such as public transit, bicycling, and walking in daily travel. In contrast, factor 3 captures the car dependence for those who enjoyed urban living. Older adults who depend on vehicles in daily travel but do not resist small living spaces, usually located in dense urban areas, belong to this category. They are called *urban car lovers* in the remaining text.

Residential Built Environment

Finally, I included two variables denoting the built environment where the respondent lives. I asked the respondent to report the zip code of the home where they lived before the pandemic. Based on the definitions of the US Department of Agriculture (2020), I assessed the residential built environment using two dummy variables: whether the residents lived in a metropolitan area, urban areas larger than 50,000 people, and whether the residents lived in a centralized area, where the primary commuting flow exists within the geographical area.

4.4.4. Analytical Strategies

I modeled the relationship between ICT and overall travel and for different activities. The "Transformations for the examination of travel and ICT" portion of Appendix C details the transformations for various ICT and travel activities. I used different approaches to address the endogeneity based on the distributions of the ICT usage variables. As shown in Table A-5 in Appendix C, some ICT usage variables had unbalanced answers and were transformed into dummy variables. Other variables had more balanced answers and were therefore treated as interval variables. I used the structural equation models to examine the relationships between ICT usage and travel behavior for models whose ICT usage variables were balanced based on the conceptual model in Figure 4.1. As for models whose ICT outcomes were binary, I used the Heckman selection models instead.[5] I used these structural models rather than more straightforward models because ICT usage is endogenous to travel behavior. Therefore, using travel behavior as predictors of ICT usage might have biased the estimations. Since I limited the travel mode of the daily travel to vehicle travel in this study, the endogeneity between mode choice and daily travel, as stated in previous studies (Zhu, 2012), was not an additional concern in this chapter. In the following sections, I further detail the modeling strategies for the two types of structural models.

Structural Equation Models

I treated the ICT usage and travel behavior variables as endogenous and all other variables as exogenous in the structural equation models (SEMs). I used the maximum likelihood estimation (MLE) method to estimate the models. Literature in social science, especially psychology, argues that an SEM using MLE is feasible for datasets with large samples whose outcome variables have balanced outcomes and have five or more categories (Rhemtulla et al., 2012).

The relationship between ICT usage and vehicle travel is captured by the standardized coefficient between these two variables, controlling for all other variables in SEMs. SEM results also show how one variable related to ICT usage is indirectly associated with vehicle travel, which is captured

[5] In the model for the relationship between travel planning applications and daily vehicle travel, I have transformed the vehicle travel to logarithm form plus 1 to make the scale of coefficients to increase the readability of the model and the consistency with other models.

by the indirect effect of that variable. Figure 4.2 illustrates how one variable is directly and indirectly related to ICT usage and vehicle travel or both. As shown in the upper and lower figures, if one variable is directly related to ICT usage, the variable is also indirectly related to vehicle travel through the channel of ICT usage.

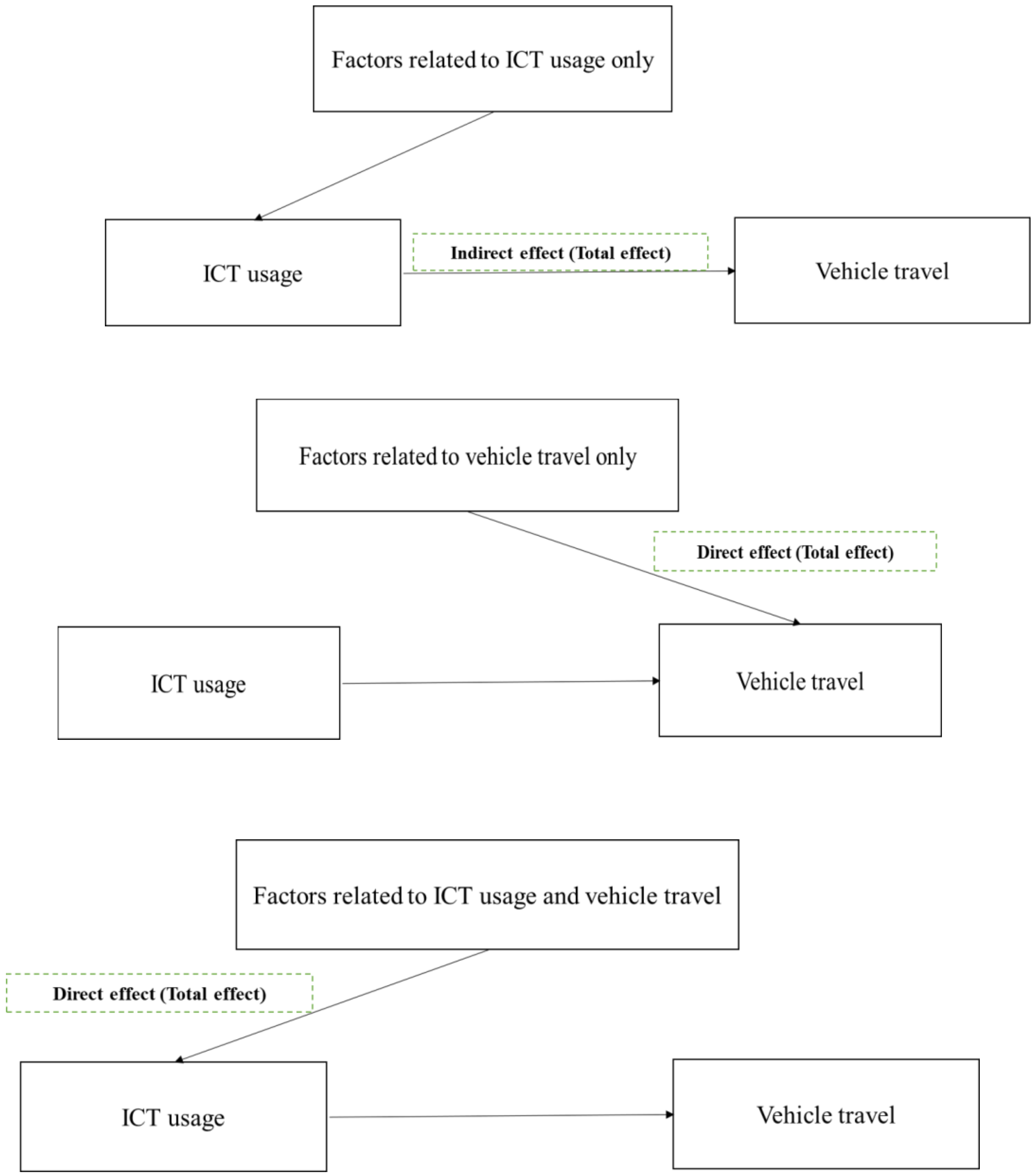

Figure 4.2 *Direct and indirect effects of different factors on ICT usage and vehicle travel in structural equation models (upper: factors related to ICT usage only, middle: factors related to vehicle travel only, and lower: factors related to ICT usage and vehicle travel)*

Heckman Selection Models

I used the Heckman selection models for models whose ICT usage outcome variables were dummy variables to address the heterogeneity problem. The model includes two integral parts, the selection and outcome models. The selection model is a probit model that predicts the probability of whether one observation falls in a specific group. In this case, the model predicts whether an older adult had used a type of ICT before. The outcome model is a Tobit model, which predicts the outcome variable outcome, travel outcomes, conditional upon the predicted result in the selection model to account for the selection bias (Heckman, 1979).

One technical requirement of the Heckman selection model is to have at least one variable in the selection model but not in the outcome model. As shown in Figure 4.1, while access to the Internet and perceptions of the technology are included in the selection models, they are not part of covariates of outcome models.

Some studies in travel behavior research have used the Heckman selection models to account for selection bias in modeling daily travel. Early applications of the Heckman selection model were used to account for missing data. Many transportation scholars have used the Heckman selection models to account for the selection bias of vehicle ownership in measuring vehicle travel, as only car owners produce vehicle travel (Huang et al., 2019; Zegras, 2010). Other scholars have used the method to compare the outcome differences across different groups due to sample selection bias. For example, Cao (2009) used the model to examine the vehicle travel differences among residents living in suburban and traditional neighborhoods. For another example, Deka (2017) applied this approach to investigate the role of car ownership on happiness, depression, and loneliness among older adults. Following the second type of application, comparing different results of two categories, I will examine how ICT usage relates to vehicle travel using the Heckman selection model.

The measurement ρ in Heckman selection models indicates the relationship between ICT usage and vehicle travel. This measurement indicates whether the sample selection bias exists, and if so, how. A statistically significant value indicates that the sample selection influences the estimation of the coefficients and standard errors in the outcome model. The sign of the number notes the direction of the influence, with a positive number indicating the sample selection's positive effect on estimations and a negative number showing the negative effect. In other words, a significantly positive ρ demonstrates that ICT usage and vehicle travel are positively correlated. In contrast, a negative sign indicates that two variables are negatively correlated.

I used the lavaan package (Rosseel et al., 2021) to fit the SEMs. The final coefficients are standardized. I used the sampleSelection package (Toomet & Henningsen, 2008) to fit the Heckman selection models. All models were estimated using R 4.1.0.

4.5. Results

This section presents the findings in two parts. The first section demonstrates the overall relationship between ICT and travel among older adults in Table 4.4. The second section further conveys how the relationship differs for various activities in Table 4.4 and Table 4.5. Table 4.4 and Table 4.5 show the modeling results for the SEMs and Heckman selection models, respectively.

Based on criteria for the model fit of SEMs summarized by Schumacker and Lomax (2016), i.e., CFI>0.90, RMSEA<0.08, and SRMR<0.05, the model-fit of SEMs shown in Table 4.4 are all acceptable. All the coefficients in the SEMs are standardized. A positive coefficient suggests a positive relationship between two variables, and a negative coefficient indicates a negative relationship between two variables.

4.5.1. Transport Disadvantages and the Digital Divide Go Hand in Hand

The first SEM in Table 4.4 displays the relationship between all daily travel and ICT activities. The coefficient of ICT usage on vehicle travel is 0.21, significantly positive, suggesting that ICT usage and vehicle travel are positively correlated. The result implies that ICT usage and vehicle travel supplemented each other among older adults, which is consistent with the results of studies on people of all ages (Kroesen & Handy, 2015; Le Vine et al., 2016; Srinivasan & Reddy Athuru, 2004; D. Wang & Law, 2007). However, it cannot compare whether the intensity is weaker with younger people. It further clarifies that people at older ages tend to have more vehicle trips, controlling for other factors. However, age is not significantly related to ICT usage. It suggests that people at older ages might have preferences for vehicle trips.

Results partly support the second hypothesis and suggest that some socioeconomically disadvantaged older adults traveled less and had less ICT usage. Controlling for other factors, some segments of older adults had less vehicle travel overall, but not higher ICT usage. These older adults had double disadvantages in daily travel in the digital era. The table demonstrates that those without college degrees, retirees, people who lived alone, and African Americans had more travel difficulties than those with college degrees, those staying in the labor force, and non-African Americans. Not having a college degree and being retired is related to lower Internet usage and lower daily travel frequencies. African Americans and those who had retired had less vehicle travel but not more Internet usage.

Nevertheless, ICT is promising in reducing the travel difficulties for those who have medical conditions that prevent them from independent mobility. As shown in Table 4.4, those who had problems walking and with self-care had lower vehicle frequency than those who were healthy. However, these older adults had higher Internet usage frequencies. Their more frequent Internet usage also contributed to more out-of-home vehicle travel, slightly attenuating their lower out-of-home travel frequency.

Results further show that tech-savviness among older adults was critical to their technology usage. The table confirms that a higher acceptance of the Internet and technology, trust in the Internet, and a lower perceived difficulty of using the Internet all boosted ICT usage.

Results also show the privilege of using the Internet in more centralized areas. Living in a centralized area is weakly related to higher ICT usage, and it also indirectly contributed to higher vehicle travel through ICT usage.

Table 4.4 Structure equation models of ICT, non-work travel frequency, and exogenous variables for all activities, shopping, and travel plan application usage

	All activities		**Shopping**		**Travel plan applications**	
	ICT usage frequency	Number of vehicle trips	Online shopping frequency	Number of shopping vehicle trips	Travel plan application usage	Number of vehicle trips
ICT activities (direct)	na	0.21***	na	0.12***	na	0.26***
Age/10						
Direct		0.04+	0.05*			
Indirect	na		na	0.01*	na	
Total						
Gender=Male						
Direct					0.10***	
Indirect	na		na	0.01+	na	0.02***
Total						
Race (Reference: non-Hispanic Whites)						
Non-Hispanic African Americans						
Direct		-0.04*		-0.05**		-0.03+
Indirect	na		na		na	
Total		-0.03		-0.05**		-0.04+
Non-Hispanic all other races						
Direct					0.07***	
Indirect	na		na		na	0.02***
Total						
Hispanics						
Direct	0.04**	0.05*			0.05**	0.04*
Indirect	na	0.01**	na		na	0.01**
Total		0.06**				0.06*
Educational attainment=With college degrees						
Direct	0.05***	0.05**		0.04*	0.08***	0.04*
Indirect	na	0.01**	na		na	0.02***
Total		0.06**		0.04*		0.06***
Annual household income (logarithm term of thousands of dollars)						
Direct				-0.03+		

Indirect	na		na		na	
Total				-0.03+		
Employment status=Retired						
Direct	-0.03*	-0.26***		-0.09***	-0.11***	-0.24***
Indirect	na	-0.01*	na		na	-0.03***
Total		-0.27***		-0.09***		-0.27***
Living in a metropolitan area=Yes						
Direct					-0.07***	
Indirect	na		na		na	0.02***
Total						
Living in a centralized area=Yes						
Direct	0.03+			0.04+		
Indirect	na	0.01+	na		na	
Total				0.04+		
Difficulty of using the Internet						
Direct	-0.43***	na	-0.20***	na	-0.25***	na
Indirect	na	-0.09***	na	-0.02***	na	-0.06***
Total		-0.09***		-0.02***		-0.06***
Acceptance of the virtual world						
Direct	0.31***	na	0.16***	na	0.21***	na
Indirect	na	0.06***	na	0.02***	na	0.05***
Total		0.06***		0.02***		0.05***
Distrust towards the Internet						
Direct	-0.03+	na		na		na
Indirect	na	-0.01+	na		na	
Total		-0.01+				
Preference for in-store shopping						
Direct	na	na	-0.19***	0.07***	na	na
Indirect	na	na	na	-0.02***	na	na
Total	na	na		0.05**	na	na
Access to the Internet						
Direct	0.06***	na		na	0.04*	na
Indirect	na	0.01***	na		na	0.01*
Total		0.01***				0.01*
Dependence on vehicles						

Direct	na	0.18***	na	0.23***	na	0.18***
Indirect	na	na	na	na	na	na
Total		0.18***		0.23***		0.18***
Sustainable suburban lovers						
Direct	na	0.04*	na		na	0.05*
Indirect	na	na	na	na	na	na
Total		0.04*				0.05*
Urban car lovers						
Direct	na		na	0.04+	na	
Indirect	na	na	na	na	na	na
Total				0.04+		
Having difficulties walking and self-caring=Yes						
Direct	0.07***		0.04*	-0.06**		na
Indirect	na	0.02***	na	0.01+	na	na
Total				-0.06**		na
Having difficulties driving=Yes						
Direct		-0.04+		-0.06**		-0.04*
Indirect	na		na		na	
Total		-0.04*		-0.06**		-0.05*
Household structure (Reference: being married)						
Living alone						
Direct	-0.03+	-0.08***		-0.09***	-0.06**	-0.08***
Indirect	na		na		na	-0.02**
Total		-0.09***		-0.10***		-0.09***
Living with others						
Direct		-0.06**				-0.06*
Indirect	na		na		na	
Total		-0.06**				-0.06***
Observations	2510					
CFI	0.98		0.97		0.98	
RMSEA	0.05		0.04		0.04	
SRMR	0.01		0.01		0.01	

Notes: *** p<0.001, **p<0.01, *p<0.05, +p<0.1. All the coefficients are standardized. Only the significant coefficients are demonstrated.

4.5.2. The Relationship Between ICT and Travel Varies for Different Activities

As Table A-1 in Appendix C confirms, the usage frequency of different technology applications varies by purpose. While older adults used online shopping, social media, online banking, and transportation planning technologies frequently in their daily life, fewer than half of the respondents in the survey had used other technologies, such as ride-hailing, video/voice calls with colleagues or friends, and e-health services. In particular, only about one in five older adults have used ride-hailing services, even though most survey respondents are relatively tech-savvy.

As expected in Hypothesis 3, the relationships between ICT usage and vehicle travel varied by purpose. Consistent with the current literature on the relationship between e-shopping and in-store shopping (Cao, 2012; Cao et al., 2010; Y. Ding & Lu, 2017; R. J. Lee et al., 2017; Zhou & Wang, 2014), online shopping frequency was positively correlated with shopping trips and total vehicle travel among older adults. Travel planning applications were also travel-stimulating. Table 4.4 presents that the usage frequency of travel planning applications is positively associated with vehicle travel frequency.

However, some other technology usage activities are not significantly related or negatively related to vehicle travel frequency for their offline equivalents. The ρ values for having video calls with friends or families, using social media daily, and delivering meals/making appointments online with the restaurants are negative and significant in Table 4.5. Results suggest that social-related technologies, such as video calls with family and friends and social media, replaced older adults' out-of-home social travel. This finding is different from the supplementary role of these applications on young people's face-to-face interactions (Delbosc & Mokhtarian, 2018). Similarly, food delivery replaced dining-out activities.

The ρ values for e-health activities and ride-hailing services are insignificant. The results suggest that these technology applications and their offline equivalents are not significantly related, or the supplementary and substitutional effects coexisted but canceled each other out.

Some segments among older adults had lower frequencies of out-of-home activities for some purposes but did not have higher usage frequency for the ICT equivalents to compensate. For example, Table 4.4 highlights that African Americans, those who did not have college degrees, and retirees among older adult respondents had lower out-of-home shopping trips. Yet, they did not have more online shopping trips. Previous studies on people of all ages (Cao, 2009b; Y. Ding & Lu, 2017; Etminani-Ghasrodashti & Hamidi, 2020; Zhou & Wang, 2014) also found the double disadvantages of in-store and online shopping for those with low incomes and less education.

Results in Table 4.5 show that some segments of older people were more likely to use only certain types of technologies. However, they did not travel more than other older adults for the equivalent out-of-home activities. For example, people of color were more likely to use video calls to communicate with their family or friends and ride-hailing applications. However, they did not have more social-related vehicle travel and vehicle trips overall.

Finally, older women had more difficulties using transportation technologies. Controlling for attitudes towards technology usage and other socioeconomic attributes, older men had more frequent usage in travel plan applications and ride-hailing services than women.

Table 4.1 Heckman selection models for the relationship between ICT usage and vehicle travel for health, dining out, social activities, and ride-hailing usage

	Health		Dining out		Social media		Videos with friends/family		Ride-hailing	
	Having used e-health technologies	Number of vehicle trips	Having used appointment or online delivery services	Number of dining-out vehicle trips	Using social media daily	Number of social activity vehicle trips	Having used video applications to meet friends/family	Number of social activity vehicle trips	Having used ride-hailing apps	Number of vehicle trips
Intercept		2.14(0.32) ***		4.05(0.45) ***		2.35(0.34) ***	0.62(0.28) *	1.84(0.31) ***	-1.91(0.46) ***	4.50(0.67) ***
Age/10			-0.12(0.04) **		-0.18(0.04) ***	0.19(0.04) ***	-0.09(0.4) **	0.18(0.04) ***		
Gender= Male	0.17(0.06) ***		0.10(0.05)+		-0.10(0.05) +				0.35(0.08) ***	
Race (Reference: non-Hispanic Whites)										
Non-Hispanic African Americans			0.15(0.09)+	-0.33(0.12) **	-0.16(0.09) +		0.39(0.08) ***	-0.38(0.09) ***	0.41(0.10) ***	
Non-Hispanic all other races							0.26(0.09) **	-0.22(0.10) *		
Hispanics	0.31(0.12) *						0.39(0.10) ***	-0.18(0.10) +	0.41(0.13) **	
Educational attainment= With college degrees	0.21(0.06) ***		0.24(0.06) ***	-0.19(0.09) *			0.09(0.05) +			
Annual household income (logarithm term of thousands of dollars)				0.09(0.05) *						
Employment status= Retired		-0.11(0.06)+	-0.21(0.06)***		0.23(0.06) ***	-0.36(0.07) ***	-0.11(0.06) +		-0.35(0.08) ***	-0.23(0.11) *

Living in a metropolitan area=Yes			0.38(0.08) ***		-0.19(0.07) **	0.15(0.08) +			0.52(0.14) ***	0.45(0.19) *
Living in a centralized area=Yes	0.15(0.08) +		0.35(0.08) ***				0.16(0.08) *		0.37(0.14) **	-0.35(0.20) +
Difficulty of using the Internet	-0.31(0.03) ***		-0.26(0.04) ***		-0.27(0.03) ***		-0.14(0.02) ***			
Acceptance of the virtual world	0.25(0.03) ***	na	0.24(0.03) ***	na	0.06(0.02) **	na	0.14(0.02) ***	na	0.42(0.04) ***	na
Distrust towards the Internet		na		na		na	0.03(0.02) +	na		na
Preference to see doctors in person	-0.19(0.04) ***		na							
Preference for social media	na				0.37(0.02) ***		-0.26(0.03) ***		na	
Access to the Internet										na
Dependence on vehicles	na	0.14(0.03) ***	na	0.20(0.03) ***	na	0.14(0.02) ***	na	0.08(0.02) ***	na	0.17(0.04) ***
Sustainable suburban lovers	na		na		na	0.04(0.02)+	na		na	0.09(0.05) +
Urban car lovers	na		na		na		na		na	
Having difficulties walking and self-caring=Yes	0.17(0.08) *	0.24(0.07) ***	0.34(0.07) ***	-0.20(0.10) +			0.11(0.07) +		0.25(0.09) **	
Having difficulties driving=Yes										
Household structure (Reference: being married)										
Living alone	-0.11(0.06)+	-0.14(0.06) *	-0.14(0.06)*	-0.18(0.09) +		-0.11(0.07) +	-0.25(0.06) ***	0.17(0.06) **		
Living with others							-0.13(0.07) +			

Observations			2510		
Rho	-0.13(0.28)	-0.72(0.10)***	-0.95(0.01)***	-0.96(0.01)***	-0.08(0.31)
Likelihood	-3385.43	-3096.48	-2904.098	-3083.177	-1040.973

Notes: *** p<0.001, **p<0.01, *p<0.05, +p<0.1. Standard errors in the parentheses. Only the significant coefficients are demonstrated. The number of vehicle trips in the ride-hailing model is the logarithm form.

4.6. Conclusions

Can ICT reduce travel difficulties for older adults? This study gives a mixed answer to the question. Overall, ICT usage supplemented rather than replaced daily out-of-home vehicle travel among older adults. That said, those who used ICT less also traveled less. Results further show that older adults with lower incomes and with less education, older adults who lived alone, and older African Americans had less daily vehicle travel and more difficulties using most technology applications. Results also show that the relationship between ICT and travel might vary based on activities. Both daily social media use and online meal delivery had dominant substitution effects on their respective offline equivalents. Moreover, some technology applications have the potential to reduce the disparities in daily travel. For example, e-health tools can help those with medical conditions to get timely healthcare treatment. Social-related technology can help people of color to maintain social interactions with friends and family.

The survey used in this study has some limitations; thus, there is a natural call for future research on the relationship between ICT and travel when better data are available. First, the survey was biased towards relatively tech-savvy urbanites. Future research should reach out to older adults who do not readily access the Internet and live in rural areas to understand their obstacles in using ICT. Second, I only surveyed people aged 60 and older in this survey. Therefore, it is impossible to conclude how the relationship between ICT and travel differs between young and older people. Future research should use large-sample surveys with detailed information on technology usage and daily travel to examine these differences. Third, the samples of the commuters and telecommuters are relatively small, which prevents me from understanding the relationship between teleworking and commuting when thousands of boomers and even members of Generation X decided to retire later. Finally, this study highlights the limitations of recall surveys, which are also demonstrated in the recent national travel survey (Federal Highway Administration, 2019). More innovative methods such as those collected by smartphones with GIS devices might help collect more informative and trustworthy travel and technology usage data. Other alternative datasets such as the American Time Use Survey are also potential sources for examining the relationship between technology usage and daily out-of-home travel.

Chapter 5. *Conclusion and Recommendations*

5.1. Introduction

As younger baby boomer generation march towards 65, the number of older adults is rapidly increasing in the U.S., contributing substantially to socioeconomic diversity among older adults in race and ethnicity, income, health status, employment status, and other traits. Yet, the built environment and transportation system, characterized by low-density suburbs and vehicle dependence, have not changed much in the last decades. Living in a single-family house with multiple cars is the so-called "American Dream" for millions of American families headed by young couples with children. This is not the case for the increasing number of families headed by older adults and near older adults who have affordability and health issues, which make the ownership and maintenance of vehicles a challenge. Though vehicle dependence and suburban living are not suitable for most older adults in the U.S., older adults do not have many choices. Nevertheless, the good news is that older adults with travel difficulties might have more options to engage in daily activities in a digital age. For example, those who give up driving can hail an Uber to go to the hospital, and those who want to speak to their children and grandchildren but live apart can click on Zoom or FaceTime to share each other's happy moments. Unfortunately, older adults systematically suffer from the digital divide compared to the younger generations. Older adults who are not tech-savvy and do not trust the Internet can hardly benefit from these modern applications.

Despite the new opportunities and challenges of transportation planning for older adults in the digital era, scholars and policymakers still lack the understanding of the core questions I raised at the beginning of the report: (a) How does the baby boomers' current daily travel differ from that of the silent generation's twenty years ago? (b) Who are the older adults that are having vehicle ownership difficulties? What factors are related to these difficulties? (c) Does information communication technology (ICT) increase older adults' daily travel? If so, for whom and which activities? The answers to these questions contribute to the current literature in transportation planning and other fields, e.g., gerontology and communication studies. It also informs transport equity theories that go beyond older adults and have implications for transportation and urban planning practices to advance older adults' transportation.

5.2. Summary of Findings

As the first research chapter, Chapter 2 investigates how baby boomers travel differently from older adults in the early 2000s. The baby boomer generation is well accepted as a generation of car lovers; however, will this vehicle dependence continue in their later life? Will their vehicle travel differ from people of the same age in the early 2000s, when smartphones and other technology were not as prevalent as today? A quasi-panel design using the 2001 and 2017 NHTS indicates no evidence for this argument controlling for socioeconomic and residential built environment factors across and within generations. Additionally, baby boomers who lived in the suburbs in 2017 did not travel more than suburbanites did in the early 2000s. However, it should be noted that retirement is directly related to more non-work vehicle trips.

This chapter also conveys the travel difficulties of some older adult groups. The vehicle travel difficulties of older adults with low incomes have persisted over the past two decades. This trend is even more prevalent for the baby boomer generation as this generation adds dramatically to the socioeconomic diversity of older people. Additionally, while vehicle dependency increases with age, vehicle ownership does not. Today, more older adults live in low-density suburbs, towns, and rural areas. This trend indicates that older adults who have transportation disadvantages, especially those living in car-dependent areas but do not have a vehicle or have a decline in vehicle ownership, might increase in the future years.

Results in this chapter contribute to the current literature on population aging and generational changes in travel behavior. The demographic and socioeconomic attributes of older adults today are evolving, but the current literature is unaware of how these attributes will possibly change older adults' travel behavior. Though a large number of studies have discussed how the new lifestyles and technology environment have changed young people's travel behavior (Blumenberg et al., 2016; McDonald, 2015; K. Wang & Akar, 2020; X. Wang, 2019), none of them have discussed how the recent changes in the social and technological environment have influenced generational differences in daily travel among older adults.

In a vehicle-dependent world, having a vehicle is still necessary for most older adults to live in low-density areas. In Chapter 3, I used 2017 NHTS to identify older adults who were likely to have difficulties in owning and maintaining vehicles. The findings suggest that households headed by retirees, low-income older adults, and women living alone had higher chance of being stuck in place. All else being equal, age itself is not a predictor of being stuck in place. However, age is a strong predictor for segments of older adults in becoming stuck in place, including retirees and women living alone.

Chapter 3 contributes to the existing research on vehicle ownership difficulties of socioeconomically disadvantaged people (Blumenberg, 2004, 2008; Blumenberg et al., 2020; Klein & Smart, 2017b) by enriching the understanding of age. The chapter demonstrates that age itself is not a contributing factor when controlling for other factors such as income, retirement, and race. However, age adds another layer of travel difficulty for some segments, such as women who lived alone and African American-headed households.

In the digital age, can ICT reduce travel difficulties for older adults? Chapter 4 reveals a mixed answer to the question. Overall, those who used ICT less also traveled less. Results further show that older African Americans, older adults with lower incomes and less education, and older adults who lived alone had lower daily vehicle travel and more difficulties using most technology applications. However, the relationship between ICT and travel might vary by activity. For example, frequent use of social media and online meal delivery services had a dominant substitution effect on their respective offline equivalents. This chapter also demonstrates that health and social technology applications can reduce the difficulties in daily travel for people of color and those with medical conditions.

This chapter contributes to the interdisciplinary gap in understanding the interaction of travel behavior and technology usage among older adults. Gerontology and communication studies scholars have substantially documented the age-based digital divide and the opportunities and challenges of promoting technology among older adults. The transportation scholarship has examined the relationship between ICT and travel, but none of the recent studies focused on older adults. This chapter contributes to the existing literature by bridging fields of digital equity and transport difficulties among the aging population. It also enriches the discussion of the relationship between ICT and travel by providing evidence from the older population.

5.3. Policy Implications

This section identifies strategies to advance a more equitable and sustainable transportation system for older adults in three ways: transportation, technology, and land use.

5.3.1 Transportation Policies

Compared to the previous generations at the same age, today's older adults, especially those in the baby boomer generation, are becoming multimodal and travel by vehicles in much the same way as the previous generation. However, the number of transport disadvantaged among older adults is on the rise. Policymakers should promote sustainable transportation and provide more transportation options and support for older adults.

Reducing Vehicle Dependence and Providing More Travel Options

This study has found increasing multimodality among the baby boomers, and more importantly, baby boomers did not travel more by vehicle than previous generations. However, the shear number of baby boomers will create an older adult population in the coming decades that is unparalled to the number of older adults at any previous time in the nation's history. Therefore, federal, state, and local governments should disincentivize vehicle usage, nudging boomers towards more sustainable travel behavior. These sustainable transportation policies will provide older adults with increased daily travel options. They will also rectify the problem of underpriced driving, by progressively increasing pricing for driving and then redistributing resources to vulnerable older adults who need additional transportation support.

Pricing Driving Correctly

The decades-long transportation practice in the U.S. makes driving underpriced for the wealthy and healthy older adults, but pose numerous challenges for those who cannot drive or have problems maintaining their vehicles. Pricing driving correctly is a fundamental step to enhance sustainability and equity in an aging society. International experiences show that the most effective way to discourage driving is to increase driving costs through such measures as roadway and parking pricing (Gärling & Schuitema, 2007; Pucher & Buehler, 2008). The prevalence of driving in the U.S. is largely due to the low price of driving. One way to reverse this trend is to change the pricing approach from fuel-based to travel distance-based. The pricing for driving has relied on the fuel tax for decades, and the scheme is neither effective in terms of revenue collection nor equitable when it comes to the costs and benefits for different social groups. Several studies have shown the promise of the vehicle miles traveled-based fee to increase the efficiency and equity in road pricing based on case studies in Oregon and Nevada (Paz et al., 2014; Zhang et al., 2009). However, given the affordability and vehicle dependence in different areas, this policy should adjust for various social groups and residents living in different locations.

Public Transportation

Providing more public transportation options for older adults can also encourage sustainable travel behavior in older adults. The U.S. transit systems in most cities are developed based on commuting patterns of residents, which tend to overlook the travel demand of older adults, most of whom are out of the labor force. The current policies funding public transit, which concentrates on providing support for those aged 60 and over living in cities, do not serve older adults who need alternative transportation support. For most older adults who live in suburban, rural areas, and small towns, public transportation is not an option. The 2017 American Housing Survey data show that most relocators among people aged 60 and older moved to places with good public transit (Li et al., 2022). Even in the cities where most transportation programs exist, public transit does not meet older adults' daily travel needs. For example, a case study in Philadelphia documents that the transit services to senior centers do not meet transit-dependent older adults' needs to access these destinations (Li et al., 2022).

Providing public transportation for older adults should focus on linking older adults' residences and activity destinations rather than solely subsidizing public transportation based on age. Current public transportation policies for older adults are neither effective nor equitable. Executing the subsidy policies adds to most transit agencies' financial burdens and is questioned for its equity implications. As a result of declining transit fare revenues for most transit agencies in the U.S, this policy adds to transit agencies' already tight budgets. As the DOT funding is slim, agencies hoping to execute greater discounts for older adults and people with disabilities should seek state and local financial support. For example, Pennsylvania makes free paratransit services for people aged 65 and over possible by using lottery revenues (U.S. Government Accountability Office, 2014). Furthermore, lottery revenue in Philadelphia County allows for free public transit for those aged 65 and older.

Nevertheless, some policymakers and scholars question the equity implications of these transit fare reduction policies, even for states and cities with additional support funding older adults' public transportation. For example, New York City implemented a reduced-fare program for older adults in the 1960s. People who registered for the program tend to be middle-income older adults (Senate Committee on Aging, 1970). In Los Angeles, older adult transit riders tend to have similar incomes and travel longer distances than younger riders (Brown, 2018). Therefore, the transit subsidy programs may not help those who are in the greatest need.

The effectiveness of mitigating older adults' transportation difficulties through paratransit services is also questionable. First, paratransit services target older adults and people with disabilities and prioritize those with physical mobility difficulties, which exclude them from the regular transit services. Therefore, many healthy older adults who have fewer alternative transportation options may not qualify for the benefits. Second, most cities' paratransit services require requests 24 hours in advance. Additionally, they are not flexible in facilitating journeys involving multiple destinations. Finally, due to the eligibility to use these services and the inconvenience, the demand for paratransit services is not large and is extremely expensive to operate.

The recently approved *Infrastructure Investment and Jobs Act* has provided possibilities to achieve these goals. The White House has acknowledged the lack of transportation options for Americans and the dominant role of the transportation sector in greenhouse emissions. The nearly $90 billion investment into public transportation, the largest in U.S. history, will help replace the aging vehicles, transition vehicles to more energy-efficient ones, expand transit networks, upgrade the transit stations, and advance the existing programs for older adults (The White House, 2021). The Act will also increase funding opportunities for bicycle infrastructure and pedestrians, and increase access to electric vehicles and charging stations.

Ride-Hailing Services

The success of many transportation network companies (TNCs) also provides some promising directions for the future of public transportation planning. Ride-hailing services and other on-demand transportation services have at least three benefits for older adults' transportation services. First, they provide flexible and convenient alternatives to vehicle services, especially for those who stop driving for health reasons, in places where public transportation is not available. Second, they can replace the underutilized transit routes or collaborate with transit agencies to supplement underutilized lines and reduce the operational costs of transit agencies. Older adults have more flexible travel schedules than young people. For times and places where there is not much travel demand, on-demand micro-transit or ride-hailing services might be better options for efficiency considerations. Finally, they can supplement transit agencies for the crucial first/last mile travel for older adults who have difficulties accessing the transit stations.

However, as ride-hailing services and taxi services disproportionally concentrate in cities, subsidies to these services mainly apply to older adults with low incomes who live in cities. At present, several programs provide subsidies or reimburse taxi and ride-hailing services for older adults. For example, the City of Gainesville, Florida, partnered with a local elder-care provider to copay ride-hailing service fees for people aged 60 and older with low income as a pilot program. This program gained popularity among low-income older adults, especially low-income female older adults (Leistner & Steiner, 2017). The City of Austin collaborated with the local ride-hailing platform RideAustin to provide free rides and discounted meal trips for older adults (Powell, 2017). Health providers and insurance companies have increased their collaborations with ride-hailing companies to copay transportation costs to non-emergency facilities (Wolfe & McDonald, 2020). These innovations will have great potential to reduce the unmet transportation needs to medical destinations for older adults, especially those who have medical conditions resulting in driving cessation.

5.3.2. Subsidizing Those Who are Stuck in Place

The current federal and local policies about transportation for older adults mainly focus on providing public transportation alternatives. The vehicle-dependent life is challenging for older adults, especially those with income and health difficulties and living in car-dependent areas. This concern was made explicit in a report to the federal government five decades ago (Senate Committee on Aging, 1970). Yet, not a single policy for older adults has focused on providing vehicle subsidies. This report reveals that though age is not a proxy of disadvantage, age adds to another layer of disadvantages in daily travel for some older adults. Results in Chapter 3 have shown that women living alone, and households comprised of retired older adults had higher probabilities of living without vehicles in non-urban areas. These results, altogether, show that the vehicle inequity in race, ethnicity, and household structure increases with age.

Providing Vehicle Subsidies

Despite the environmental concerns, providing subsidies for vehicles is still a feasible and effective short-term solution to help older adults age in place. Making the cities and communities multimodal and less vehicle-dependent will not happen in the short term. Before a car-free future, in which a person did not need a car to get to daily destinations, came true in most places in the U.S., most older adults still needed vehicles to travel to work and non-work destinations. Therefore, vehicle subsidies that help older adults with lower incomes maintain their vehicles can help older adults successfully age in place and engage with various activities.

Unfortunately, the current vehicle subsidy programs in most states and cities in the U.S. mainly focuses on getting low-income households to employment(Blumenberg, 2004; Blumenberg & Pierce, 2014; Klein, 2020). This funding scheme, however, naturally exclude low-income older adults, who are mostly out of labor market. These programs have not fully acknowledged the risks of giving up vehicles due to the decline of income and social shocks over the life course, especially for those who have retired. Due to the climate change concerns, it is also necessary to invest more to updating many older adults’ aging vehicles to those using clean energy. The local agencies and even the federal government should design subsidy programs that can help older adults with lower incomes get safer and more energy-efficient vehicles.

Other On-Demand Vehicle Alternatives

On top of vehicle subsidies, volunteer driver programs and on-demand transportation services provided by TNCs are two potential ways to supplement households without vehicles or active drivers. Volunteer driver programs are locally administrated programs that match volunteer drivers with prospective older adult passengers who need rides. Volunteer driver programs are supported financially by many Department of Health and Human Services (HHS) and Federal Transit Administration (FTA) programs. As a reward, volunteer drivers get free insurance for their vehicles through these programs. In 2014, based on the National Volunteer Transportation Center (Kerschner, 2015), there were more than seven hundred volunteer driver programs with more than 50,000 volunteer drivers in the U.S.

The success of these programs requires collaborative efforts from the private sectors, public agencies, and non-profit organizations. At present, the volunteer diver programs are relatively small and have difficulty expanding due to the insufficient funding to cover insurance costs for volunteer drivers (U.S. Government Accountability Office, 2014). A survey of officials from four states in the U.S. discloses that very few services are available for older adults in rural areas (U.S. Government Accountability Office, 2014). Similarly, subsidies for TNC services also require strong funding support from the local transit agencies or local governments. Another limitation of the current transportation provision is that most on-demand transportation services focus on essential daily activities, especially healthcare activities. Trips related to healthcare for older adults can earn funding sources from various federal agencies, including HHS, Medicaid, and the Health Resources and Services Administration. However, these programs are still short of fulfilling other life-enriching trips, such as social trips and recreation. The transportation services should target more on preventative activities, such as social and recreational activities, which promote healthy and active lifestyles, rather than just trips to healthcare treatments. Moving these programs forward requires more funding from community development agencies, non-profit agencies, and local governments.

Increasing Funding for Driver's Safety Education

Rosenbloom (2009) suggests that improving older driver's safety may be the most feasible way in the short run to address their travel difficulties, as the development in age-friendly transportation systems and communities could barely keep pace with the growth of the aging population in the U.S. Though not discussed in this dissertation, older adults may be more likely to getting injured or killed in car accidents due to their cognitive or health limitations than their younger counterparts. The primary channel of driver's safety education is the online platform. These platforms, now, are mostly run by local agencies or non-profit agencies like AARP. For example, AARP has developed free courses about vehicle technology and driving safety with the American Automobile Association. Though some federal agencies like AOA have the intention to collaborate with AARP and other organizations to promote driver safety education for older drivers, these agencies reported that the lack of funding prevented them from sustaining these efforts (U.S. Government Accountability Office 2014). Therefore, increasing funding sources for mandating and updating safety education and providing funding sources to update older adults' vehicles with safety devices and features should be another critical funding area of federal and local governments.

5.3.3. Narrowing the Digital Divide

Results demonstrate that ICT development has reduced vehicle travel demand among older adults in the last decades. It also helps those with physical conditions access various opportunities online without time and space constraints. This section offers several suggestions for making technology accessible to all older adults.

Technologies can help advance transport equity, especially for those who have difficulties in daily travel. As shown in Chapter 4, older adults who had difficulties in daily travel, especially people of color and those with health conditions, tended to use technology related to health and social purposes more often. Various federal and local governments and aging-related organizations can seize this opportunity to promote virtual access to various urban opportunities. For example, Medicare started to reimburse telehealth costs during the pandemic (Centers for Medicare & Medicaid Services, 2020). This strategy might mitigate health disparities among older adults based on race. Non-profit agencies like AARP and local Area Agencies on Aging (AAAs), together with various types of businesses, have all made efforts to provide older adults with tutorials for various ICT technologies, offer online services, visits, and consultations, and collect online information resources for older adults (GeriPal, 2020). These platforms and services, including many emerging during the pandemic, provided older adults with more options to access social, economic, and cultural events and destinations. The future provision of urban services and products should also enhance their online equivalents so that older adults, especially those without sufficient income and health capabilities, can still benefit.

However, this study reveals the gender-, income-, and education-based digital divide among older adults. Strategies to narrow the digital divide require equitable technology access and improving the technology literacy of older adults suffering from digital divide.

The 2021 Infrastructure Investment and Jobs Act takes note of the spatial inequity of technology infrastructure access and the high costs of Internet access. The Act aims to address these inequities with a $65 billion investment (The White House, 2021). Narrowing down the digital divide necessitates new policies to subsidize programs for older adults with lower incomes and who live in rural areas, as they have substantial difficulties accessing and paying for stable and high-speed wireless connections.

A knowledge-based digital divide is another challenge for older adults. Chapter 4 confirms that the perceived difficulty and the lack of trust towards the Internet significantly relate to lower technology usage. In the short term, transportation agencies or other service providers can offer options and help for those who are not tech-savvy. Some cities have started to provide hotlines for older adults to plan their trips. Also, companies like GoGoGrandparent enable older adults to use their landlines to hail an Uber.

Mobility management programs are one of the new funding areas of FTA since MAP-21. Mobility management programs help older adults identify available transportation resources and access to these resources. The U.S. Government Accountability Office (2014) listed three types of mobility management programs that are helpful for older adults to recognize their available alternative transportation resources: (a) One-call and one-click centers which help residents recognize available transportation resources through online tools, smartphone applications, and hotlines. (b) Mobility management technicians who provide information and trip plan services for residents in their regions. (c) Travel training programs which involve residents through education, providing them with information about available transportation resources in their communities, and mobilizing technologies to plan their travel routes. These programs are relatively new, and only a few cities with rapidly growing populations of older adults have implemented these programs, e.g., St. Johns County in Florida, and Dallas, Texas (U.S. Government Accountability Office, 2014).

In the long term, governments, non-profit agencies, employers, and communities can promote technology education for older adults, including providing hands-on training on how to use mobility management tools and other technology platforms. The next generation of older adults, baby boomers, are more tech-savvy than their parents due to the higher exposure to ICT. To this end, programs developed to increase the technology literacy of older adults through employers, community education, and social networks can help them benefit from the ICT tools and reduce travel difficulties.

5.3.4. Creating More Age-Friendly Communities

Eventually, sustainable and equitable travel among older adults requires the systematical change of the built environment. The unsustainable and unjust transportation system mentioned above stems from the decades-long transportation and land use policies in the U.S., which favor vehicle travel and urban sprawl. Evidence from all chapters in this report confirms the urgency and opportunities to create more walkable and accessible communities.

The changing lifestyle of older adults after retirement calls for land use reconfigurations of the current neighborhoods. Chapter 2 details that those who were unemployed and retired had more non-work travel, and baby boomers had even higher demand than people at the same age two decades ago. Additionally, the travel distance of the baby boomer generation for work and non-work purposes had both increased in the last two decades. Given the increasing number of retirees in the coming decades, more compact, mixed-use communities with various facilities will help older adults to reduce vehicle travel after retirement. A more compact and mixed-use neighborhood will also create more spaces for business and workplaces, encourage many older residents to reduce the commuting distance, and allow older adults to save commuting time and stay in the labor force longer. Moreover, the COVID-19 pandemic has allowed an increased amount of older adults to be more active than before.

However, in the past decades, spatial inequality of age-friendliness has existed in many U.S. cities. Age-related amenities have mainly grown in urban areas rather than suburban or rural areas. This further increases the spatial inequity of age-friendliness between urban and non-urban areas. One reason is that aging-related facilities are primarily growing in the urban and suburban areas due to the greater financial capacities of these places (Warner et al., 2017; Warner & Zhang, 2019). Chapter 2 has found that all else being equal, baby boomers living in urban areas have more vehicle trips than people at the same age in the silent generation, but those living in the suburbs did not show this pattern. It suggests that planners need to promote the diversity and quantity of age-related facilities in suburbs and rural areas. Increasing the density of these facilities will also facilitate the configuration of transportation services in these areas.

Building age-friendly communities is a collaborative effort. Making the communities supportive to older adults requires increasing its density and diversity of land use. It also calls for changes in the road system and urban design features in the neighborhoods, for example, more benches and green spaces, traffic-calming areas, and broader sidewalks, to make every older adult feel comfortable, safe, and engaged in the neighborhood (Winick & Jaffe, 2014).

Funding support is fundamental to nurturing such communities. Therefore, relevant federal and local agencies can promote funding schemes to fund initiatives that make communities more age-supportive. Some cities and states have started to foster these initiatives. For example, the Atlanta Regional Commission has developed the Lifelong Communities project to make healthier and more livable communities over everyone's life course. Florida and Indiana have also developed statewide initiatives to increase the age-friendliness of the neighborhoods (Winick & Jaffe, 2014). More importantly, relaxing the zoning mandates and building codes to allow more mixed development and flexible land use based on older adults' needs is the precondition to the success of age-friendly communities. The relaxation of these land use regulations would also benefit older adults in improving housing affordability. For example, Foster City and Howard County in Maryland changed the zoning codes in some communities to build smaller and more affordable housing units for older adults (Baker et al., 2014).

In addition to the efforts from the planning department, engaging the community and understanding their needs require collaborations with social service providers. Working with different agencies gives planners a better idea of the desired configuration and functions of the communities. This collaboration helps offer facilities and services tailored for older adults, such as age-friendly parks, community transportation, and meal delivery services.

5.3.5. Moving Forward: A Multi-Departmental, Multi-Level Initiative

Promoting accessibility capability requires multi-departmental and multi-level collaborations. Despite generous support from the federal government to invest in transportation, technology, and affordable housing, the funding expenditures should balance the needs of different regions, social groups, and funding areas. Nevertheless, it provides an opportunity to reconsider the planning implications for an aging society.

Reducing the administrative fragmentation and providing more comprehensive and tailored transportation services for older adults requires the federal government, local governments, and regional and community planners to be aware that transportation, housing, land use, technology, and health policies for older adults all aim at one common goal: to promote successful aging for all. Envision an equitable society where every older adult lives in an environment fitting their life course, income status, and health status. In this regard, transportation planners also have to consider how other factors might influence older adults' travel demands and the resulting transportation services and the social and health impacts these services bring about.

Given the tightened revenues from the fuel tax and increasing investments in equity-enhancing projects, collaborating with other agencies, e.g., the Department of Health and Human Services, the Department of Energy, and the Environmental Protection Agency, can not only make the age-friendly planning more cost-efficient but also achieve the co-benefits of all departments. A committee consisting of members from all the above agencies focused on improving transportation and health among older adults can help achieve this goal. The federal government has acknowledged the necessity of this task force (U.S. Government Accountability Office, 2014).

Together with the regional representatives, members from these agencies should mandate age-friendliness and transportation service provision assessment, which involves public transportation, paratransit services, and assessments on the unmet vehicle needs in low-density areas. Based on the assessment results, allocated funding sources should help fulfill the unmet services in underserved places and among older adults.

At the local levels, transit agencies, metropolitan planning organizations (MPOs), state-level departments of transportation, and small towns and localities also need to work with the aging-related social service providers, the AAAs, and non-profit agencies for place-sensitive solutions to improve older adults' transportation services. A small proportion of federal funding can be allocated for MPOs and local agencies to hire professionals with expertise in age-friendliness assessment or develop new joint offices aimed at aging-friendly planning.

Funding allocation is the key to advancing transport equity for older adults. A successful age-friendliness improvement project involves strong community participation, leadership, and new funding schemes, e.g., private-public partnerships or land value capture. Due to local variations in financial capacity, federal governments can also provide technical or financial support to leverage funding sources. The majority of the funding would be allocated to small or medium MPOs and other smaller localities for more urgent issues which were not covered in the current policies, e.g., vehicle subsidies programs for older adults with low incomes, volunteer driver's programs in rural areas, and smart rural communities for aging. A limited amount of funding can be allocated to large MPOs to attempt innovative ideas in age-friendly planning, such as age-friendly transit-oriented development, age-inclusive housing initiatives, ride-hailing and transit integration programs, and show small and medium MPOs the future of long-term age-friendly planning models.

5.4. Future Research Directions and Policy Takeaways

This report contributes to the existing literature by providing a big picture of transportation planning opportunities and challenges for older adults at the national level. Given the rapidly increasing number of older adults in the country and the relatively small amount of research exploring older adults and transportation, this report calls for five research areas related to older adults and transportation planning and urban planning. It also has some fundamental policy implications for transportation and urban planning for an aging society.

5.4.1. Future Research Directions

First, the analysis in this study masks the variations across places, travel modes, and activities. The demographic profiles of older adults and local transportation policies are quite divergent in the different regions of the U.S. For example, while many Western and Southern cities are vehicle-dependent and have many older adults living in suburbs and rural areas, large transit-friendly cities on the east coast, such as Philadelphia, provide free bus rides for older adults. Even so, the operational times and transit routes of these cities might not fully address the travel needs of older adults. More future research focusing on travel difficulties of older adults using different travel modes for various activity purposes in multiple cities can provide a more nuanced understanding of the generalizability of the findings of this dissertation.

Second, this project calls for research using more diverse datasets and methodologies to understand older adults' transportation difficulties and the health implications. This report confirms that residential location, transportation, and technology usage all matter in older adults' quality of life. However, datasets covering all the above aspects are still rare, including those targeting older adults, such as the Health and Retirement Study and the National Health and Aging Trends Study. The older adult sample is undersampled in national transportation survey studies like the NHTS, and have limited information on residential location and technology usage for various activities. The sample bias problem is even more evident in the online survey, which tends to overlook all older adults who are not tech-savvy. Though this project touches upon the intersection of technology, transportation, and land use, all data sets being used in the dissertation cannot unpack the complex relationship directly.

Two directions are promising in improving data quality. First, future research can use a quasi-experiment study design to evaluate a new infrastructure improvement program's impact on older adults' social and health outcomes. Scholars can collect the data on social and health outcomes, e.g., life satisfaction and housing affordability, after the new programs are implemented, e.g., the provision of on-demand micro-transit for older adults.

Conducting qualitative studies are another way to unpack the relationship. Researchers can identify the marginalized communities with old ages and examine how their residents' daily travel and technology use activities interact and how those activities contribute to their future residential and travel decisions and perceived health.

Third, a comparison of different ages and generations can demonstrate more clearly to what extent older adults travel differently than younger groups. This type of research requires representative, ideally longitudinal, samples. Such data can be coupled with the demographic models to unravel the period, age, and cohort's roles, shedding light on how the interaction of age and other demographic factors influence travel outcomes over life course.

Fourth, though this dissertation gives a theoretical framework to understand the role of transportation, land use, and technology through the lens of social equity and successful aging, research on the complex relationships among factors in the residential environment and subjective well-being remains rare. This observation is also clear in a literature review (Li, 2020). Using more rigorous methods and various measurements to bridge the relationship between transportation and health or other social outcomes can help policymakers and relevant departments to recognize the role of transportation in older adults' development, with age-friendly urban design fostering the codesign of transportation policies for older adults.

Last but not least, this dissertation asks for more research into the policymaking decisions concerning older adults' transportation services. Transportation issues have been more complex than ever due to sustainability and equity pressures. Older adults' transportation needs might be a priority for some states and localities, but not for others where older adults only make up a small proportion of the population. More complex, MPOs and transit agencies are not the only transportation service providers for older adults. The local social service providers, AAAs, are the key provider for such services. While some AAAs are non-profit agencies, some others are subagencies of the local governments. Very few of them are part of the MPOs. In this sense, AAAs, MPOs, transit agencies, and other providers might have different goals, strategies, funding sources, and clients when providing older adults' transportation services. Future research should explore the complexity of policymaking in transportation provision for older adults at local levels and how the local agencies interact with various state and federal stakeholders. Such studies will also show how governmental organizations impact age-friendly planning policy production and funding effectiveness.

5.4.2. Policy Takeaways

This dissertation also has several crucial policy implications. First, policymakers might need to reconsider the assumption that most baby boomers are life-long car lovers, and thus travel more by vehicle than the previous generation. In this way, instead of funding more highway development projects, policy makers should consider pricing driving correctly, and encourage older adults to travel using more sustainable modes, and use virtual means to replace travel when it is possible.

Second, today's age-based transportation funding for public transit and paratransit is neither equitable nor cost-effective. Therefore, future policies should be based more on older adults' diverse needs, and provide more options for those living in different places. In particular, for those who live in the suburban and rural areas, federal and local governments should support more on-demand transportation options, and vehicle subsidies, to avoid older adults stuck in place.

Third, in the digital era, narrowing the digital divide is essential to mitigate older adults' travel difficulties. To make older adults benefit more from the digital world, the federal government, local governments, and communities should invest more to make affordable high-speed Internet accessible for all older adults, including those living in rural areas. They also need to strengthen technology education for older adults through various learning programs and community centers. Many older adults still suffer from the digital divide, requiring the governments to collaborate with private sectors and non-profit sectors to subsidize older adults to use alternative ways, e.g., land-line phone, to access technological services, e.g., ride-hailing and travel planning.

Finally, improving older adults' accessibility to various destinations needs efforts beyond the transportation department. It also requires massive efforts and collaboration from other departments, such as public health and social services, housing, land use, and technology. Therefore, planning age-friendly transportation system, communities, and cities require a lot more multi-level and collaborative governance, involving multiple stakeholders and different levels of agencies. Such a collaboration will not only improve older adults' accessibility in various ways, but also will potentially improve the cost-effectiveness in improving older adults' subjective well-being.

Appendix A: Appendix for Chapter 2

Sampling methodology changes of NHTS and potential impacts

There are some changes in sampling and data collection in three years' NHTS data. First, unlike the 2001 and 2009 surveys, which used the randomly selected telephone numbers, the 2017 surveys randomly sampled households based on their home addresses (Federal Highway Administration, 2019). The 2001 and 2009 surveys undersampled those who only had cellphones. Nevertheless, this is less influential to older adults. Second, the 2017 survey also distinguishes itself from the prior surveys by the interview approach. The respondents had two options to answer the 2017 survey: online or through the telephone. In contrast, the 2001 and 2009 surveys used in-person and telephone interviews. As noted by FHWA, the online survey might underreport the short trips or stops along the trip (for example, getting gas on the way to work) (Federal Highway Administration, 2020). Third, the 2017 survey changed the way of calculating the vehicle travel distance. For the first time in NHTS history, the 2017 NHTS used a geocoding tool to calculate the distance of the shortest network path of trips rather than using the self-reported distance as prior surveys. Nevertheless, Federal Highway Administration (2020) notes that the difference due to the calculation method could be adjusted by multiplying the 2017 NHTS trip distances by 1.1.

There are some other limitations of the data in answering the research questions. First, all surveys excluded older adults who live in nursing homes. Second, though all surveys asked older adults' web use, the 2001 survey only asked household heads, and there are too many missing answers among older adults. Therefore, the NHTS data is not a desirable data set to examine the technology's role in travel behavior over time. Third, as noted before, the NHTS data is a cross-sectional data set, and surveys have different samples in each survey year. Though it is a desirable data set to examine the travel behavior change of older adults from 2001 to 2017 at the national level, it is incapable of investigating the relationship between individuals' life-cycle events (such as retirement and losing the partner) and vehicle travel changes.

Data cleaning and measurements

I merged the travel trip, individual, and house data files based on the household and person identifiers and deleted those whose vehicle travel distance and travel mode records were missing. I deleted trips made by airplanes and those trips whose distances are longer than 99.5% of all non-airplane trips (137.1 miles for 2001, 140 miles for 2009, 169 miles for 2017). I multiplied the travel distance of 2017 trips by 1.1 to account for the calculation differences across years. The final sample size of the 2001 and 2017 data are 25,985 and 81,980, respectively. The descriptive statistics of the surveyed samples aged 56–71 in 2001 and 2017 are shown in Table A-1.

Table A-1 Descriptive statistics of the 2001 and 2017 samples aged 56–71

	The silent generation 2001	**The baby boomer generation 2017**
Vehicle Miles Traveled (VMT) per capita on the travel day		
Average	36.67	38.34
Standard deviation	42.79	49.24
VMT=0	1,189	4,208
Non-work VMT per capita on the travel day		
Average	29.30	29.86
Standard deviation	39.73	46.20
Non-work VMT=0	3,365	11,395
Vehicle trips per capita on the travel day		
Average	4.31	3.93
Standard deviation	2.63	2.50
Non-work vehicle trips per capita on the travel day		
Average	3.62	3.28
Standard deviation	2.72	2.61
The average distance of vehicle trip		
Average	9.71	11.36
Standard deviation	12.58	16.37
Average distance of non-work vehicle trip		

Average	8.99	10.40
Standard deviation	12.32	16.39
Sex		
Male	0.47	0.46
Female	0.53	0.54
Age		
<65	0.61	0.57
>=65	0.39	0.43
Race and ethnicity		
Non-Hispanic Whites	0.87	0.82
Non-Hispanic African Americans	0.04	0.07
All other non-Hispanic races	0.05	0.05
Hispanics	0.03	0.06
Weighted household income (thousands U.S. dollars)		
Average	46.51	52.09
Standard deviation	27.12	34.46
Employment status		
Employed	0.47	0.45
Unemployed or retired	0.53	0.55
Maximum educational attainment		
Lower than high school	0.11	0.04
High school	0.39	0.21
Associate or equivalent	0.23	0.32
College and higher	0.26	0.44
Living alone		
Yes	0.16	0.21
No	0.84	0.79
Household size		
Average	2.12	2.04
Standard deviation	0.90	0.86
Population density of the block group (thousands persons/square mile)		
Average	3.85	3.40

Standard deviation	5.95	4.87
Urban indicator		
Urban	0.10	0.10
Suburban	0.20	0.21
Secondary city	0.20	0.18
Rural	0.50	0.51
Population size of the Metropolitan Statistical Area (MSA) of the home address		
In an MSA of less than 250,000	0.17	0.17
Not in a metropolitan area	0.23	0.18
In an MSA of 250,000 - 499,999	0.16	0.11
In an MSA of 500,000 - 999,999	0.10	0.14
In an MSA of 1,000,000 – 2,999,999	0.11	0.14
In an MSA of 3 million or more	0.24	0.26
Health		
Having health conditions resulting in giving up driving		
Yes	0.02	0.02
No	0.98	0.98
Having health conditions resulting in asking others for help		
Yes	0.06	0.04
No	0.94	0.96
Travel day		
Weekday	0.72	0.78
Weekend	0.28	0.22
Observations	25,985	81,910

Table A-2 Two-way ANOVA test on the interaction of the survey year and variables of interest

	Personal Vehicle Miles Traveled	**Vehicle trips**	**Average vehicle trip distance**
Sex			
All trips 56-71	$p<0.001$	$p<0.001$	0.59

Non-work trips only 56-71	0.08	p<0.001	0.73
Non-work trips only 65-71	p<0.001	p<0.001	0.51
Age			
All trips	p<0.001	0.01	0.28
Non-work trip only	p<0.001	0.30	0.17
Race and ethnicity			
All trips	p<0.001	p<0.001	0.12
Non-work trip only	p<0.001	p<0.001	0.07
Non-work trips only 65-71	0.03	p<0.001	0.89
Annual household income ($)			
All trips	p<0.001	p<0.001	0.09
Non-work trip only	0.13	0.68	0.04
Non-work trips only 65-71	0.81	0.01	0.16
Employment status			
All trips	p<0.001	p<0.001	p<0.005
Non-work trip only	p<0.001	0.13	0.93
Non-work trips only 65-71	p<0.001	p<0.001	0.37
Educational attainment			
All trips	p<0.001	0.21	p<0.005
Non-work trip only	0.01	p<0.005	0.05
Non-work trips only 65-71	0.65	0.22	0.17
Living alone			
All trips	0.03	p<0.001	0.11
Non-work trip only	0.62	p<0.001	0.18
Non-work trips only 65-71	0.91	0.01	0.39
Population density at the census block level (persons/squared mile)			
All trips	0.54	p<0.005	0.07
Non-work trip only	0.16	0.08	0.05
Non-work trips only 65-71	0.35	0.34	0.46

Urban indicator			
All trips	p<0.001	p<0.001	0.37
Non-work trip only	0.01	p<0.001	0.10
Non-work trips only 65-71	0.17	p<0.001	0.88
The population size of the Metropolitan Statistical Area (MSA) of the home address			
All trips	p<0.001	p<0.001	0.05
Non-work trip only	0.03	0.1	0.03
Non-work trips only 65-71	0.10	0.11	0.21

Notes: Grey cells indicate that the p-values of two-way ANOVA tests of the survey year (2001 versus 2017) and variables of interest are smaller than 0.05 and should be included as an interaction in the regression models.

Data description and regression tables

Table A-3 Generational changes in individual, socioeconomic, and built environment characteristics between the baby boomer generation and the silent generation aged 56–71(%)

	The silent generation 2001	**The baby boomer generation 2017**
Sex		
Male	46.6	47.4
Female	53.4	52.6
Age		
>=65 years	62.6	61.5
< 65 years	37.4	38.5
Race and ethnicity		
Non-Hispanic Whites	78.2	68.7
Non-Hispanic African Americans	11.3	12.6
All other non-Hispanic races	4.6	6.3
Hispanics	5.9	12.4
Annual household income		
$25,000 and less	26.1	21.2
$25,000–$34,999	16.1	9.7
$35,000–$49,999	20.9	12.4
$50,000–$74,999	17.2	17.2
$75,999–$99,999	9.1	13.0
$100,000 and more	10.6	26.7
Employment status		

Employed	45.6	49.0
Unemployed and retired	54.4	51.0
Maximum educational attainment		
Lower than high school	14.4	6.5
High school	40.1	24.4
Associate or equivalent	20.1	31.5
College and higher	25.4	37.6
Living alone		
Yes	84.3	78.8
No	15.7	21.2
Population density at the census block level (persons/squared mile)		
<500	31.0	26.5
500–1,999	19.5	19.7
2,000–3,999	17.6	18.7
4,000–9,999	22.4	23.2
>=10,000	9.5	11.9
Urban indicator		
Urban	14.4	17.8
Suburban	23.4	21.7
Secondary city	17.5	18.8
Small town and rural	44.8	41.7
The population size of the Metropolitan Statistical Area (MSA) of the home address		
Not in a metropolitan area	22.2	16.5
In an MSA of less than 250,000	7.5	9.2
In an MSA of 250,000 – 499,999	8.3	9.0
In an MSA of 500,000 – 999,999	8.2	12.0
In an MSA of 1,000,000 – 2,999,999	19.7	19.6
In an MSA of 3 million or more	34.2	33.7

Notes: All values in the cells are weighted by final personal weights.

Table A-4 vehicle miles traveled and vehicle trips of the baby boomer generation and the silent generation aged 56-71 with different individual, socioeconomic, and built environment characteristics

	Personal vehicle miles traveled	**Vehicle trips**	**Average vehicle trip distance**

	The silent generation 2001	The baby boomer generation 2017	The silent generation 2001	The baby boomer generation 2017	The silent generation 2001	The baby boomer generation 2017
Sex						
Male	41.6	37.5	4.4	3.7	10.8	11.8
Female	32.7	31.9	4.1	3.7	8.9	9.7
Age						
>=65 years	33.3	33.1	4.3	3.7	8.8	10.1
< 65 years	39.1	35.1	4.3	3.7	10.5	11
Race and ethnicity						
Non-Hispanic Whites	38.7	37.4	4.4	3.9	9.9	11.1
Non-Hispanic African Americans	26.1	26.4	3.2	3.4	8.4	9.1
All other non-Hispanic races	37.9	30.1	4.2	3.1	10.1	10.6
Hispanics	31.7	29.0	3.7	3.4	10.5	9.7
Annual household income ($)						
$25,000 and less	29.1	23.1	3.8	3.1	8.8	8.3
$25,000–$34,999	39.4	29.3	4.4	3.7	9.9	9.2
$35,000–$49,999	38.4	35.1	4.5	3.9	9.7	9.9
$50,000–$74,999	40.2	35.8	4.5	3.8	10.3	10.8
$75,999–$99,999	41.0	39.6	4.4	3.9	11.3	11.4
$100,000 and more	41.0	41.0	4.5	3.8	10.4	12.4

Employment status						
Employed	40.4	37.1	4.3	3.7	10.5	11.4
Unemployed and retired	33.6	31.7	4.2	3.7	9.2	9.8
Maximum educational attainment						
Lower than high school	31.9	24.3	3.4	3	9.5	10.2
High school	36.7	32.0	4.2	3.5	9.4	10.7
Associate or equivalent	38.3	35.4	4.5	3.8	10.3	11.5
College and higher	38.8	36.4	4.6	3.9	9.5	11.2
Living alone						
Yes	30.4	26.2	4	3.5	8.4	8.9
No	38.2	36.6	4.3	3.8	10.1	11.1
Population density at the census block level (persons/squared mile)						
<500	47.0	47.8	4.3	4	12.3	13.5
500–1,999	38.1	36.2	4.6	3.9	9.4	10.7
2,000–3,999	35.7	32.1	4.5	4	9.5	9.3
4,000–9,999	29.9	28.3	4.2	3.7	10.4	12.4
>=10,000	20.8	19.1	3	2.4	7.6	9.3
Urban indicator						
Urban	23.8	21.0	3.4	2.8	7.9	8.9
Suburban	34.3	32.7	4.4	3.9	8.7	9.4
Secondary city	32.4	28.3	4.4	3.7	8.3	9.0
Small town and rural	44.3	43.8	4.4	3.9	11.5	12.7
Population size of the Metropolitan Statistical Area (MSA) of the home address						
Not in an MSA	44.2	43	4.4	4.0	11.6	12.3
In an MSA of less than 250,000	39.2	35.4	4.7	3.9	9.8	10.7

In an MSA of 250,000 – 499,999	38.6	37.8	4.4	3.9	9.2	10.9
In an MSA of 500,000 – 999,999	33.4	34.0	4.4	3.8	8.3	10.2
In an MSA of 1,000,000 – 2,999,999	35	33.2	4.3	3.8	9.1	10.0
In an MSA of 3 million or more	33.4	29.9	4	3.3	9.7	10.4

Notes: All values in the cells are weighted by final personal weights. Grey cells indicate that the difference between 2001 and 2017 values are statistically significant using weighted two-sample means t-test (p<0.05).

Table A-5 Regression models on non-work vehicle trips and vehicle miles traveled for all and non-work vehicle trip distance for those who made vehicle trips for those aged 56-71 in 2001 and 2017

Variables	**Personal non-work vehicle miles traveled per day Tobit**	**Non-work vehicle trip negative binomial**	**Non-work average vehicle trip distance log-linear**
Year: 2017	-0.481***	-0.165***	-0.052
	(0.068)	(0.028)	(0.036)
Sex			
Reference: male			
Female	0.045***	0.023*	-0.058***
	(0.012)	(0.011)	(0.007)
Female × 2017		0.029*	
		(0.013)	
Age			
Reference: <65			
>=65	0.188***	0.076***	-0.032***
	(0.026)	(0.006)	(0.007)
>=65 × 2017	-0.062*		
	(0.030)		
Race and ethnicity			
Reference: Non-Hispanic Whites			

Non-Hispanic African American	-0.314***	-0.146***	0.024
	(0.067)	(0.032)	(0.014)
Other non-Hispanic races	-0.152**	-0.058*	0.035*
	(0.056)	(0.025)	(0.016)
Hispanic	-0.112	-0.028	0.034*
	(0.071)	(0.033)	(0.016)
Non-Hispanic African American × 2017	0.284***	0.141***	
	(0.072)	(0.034)	
Other non-Hispanic races × 2017	0.058	-0.01	
	(0.064)	(0.029)	
Hispanic × 2017	0.154*	0.048	
	(0.077)	(0.036)	
Household income			
Weighted household income (thousands U.S. dollars)	0.002***	0.0002*	0.001***
	(0.0002)	(0.0001)	(0.0001)
Employment status			
Reference: employed			
Unemployed or retired	0.577***	0.367***	0.033***
	(0.025)	(0.006)	(0.007)
Unemployed or retired × 2017	0.317***		
	(0.029)		
Maximum educational attainment			
Reference: lower than high school			
High school	0.194***	0.129***	0.016
	(0.043)	(0.020)	(0.024)
Associate or equivalent	0.334***	0.218***	0.012
	(0.048)	(0.022)	(0.027)
College and higher	0.264***	0.206***	-0.025
	(0.046)	(0.021)	(0.025)
High school × 2017	0.082	-0.01	0.045
	(0.061)	(0.029)	(0.034)
Associate or equivalent × 2017	0.099	-0.026	0.058
	(0.064)	(0.030)	(0.036)
College and higher × 2017	0.225***	0.025	0.080*
	(0.062)	(0.029)	(0.035)

Household composition			
Living alone			
Reference: No			
Yes	-0.116***	-0.009	-0.095***
	(0.019)	(0.016)	(0.011)
Yes×2017		0.045**	
		(0.017)	
Household size	-0.008	0.005	0.001
	(0.009)	(0.004)	(0.005)
Residential built environment			
Population density			
Population density of the block group (thousand persons/square mile)	-0.047***	-0.015***	-0.013***
	(0.002)	(0.001)	(0.002)
Population density of the block group (thousand persons/square mile)×2017			0.002
			(0.002)
Urban indicator			
Reference: small town and rural			
Secondary city	-0.099**	0.085***	-0.296***
	(0.034)	(0.015)	(0.011)
Suburb	-0.087*	0.072***	-0.254***
	(0.036)	(0.015)	(0.010)
Urban	-0.326***	(0.025)	-0.289***
	(0.057)	(0.025)	(0.018)
Secondary city × 2017	-0.079*	-0.01	
	(0.039)	(0.017)	
Suburban × 2017	-0.096*	-0.026	
	(0.041)	(0.017)	
Urban × 2017	0.003	0.033	
	(0.059)	(0.025)	
Metropolitan area size			

The population size of the Metropolitan Statistical Area (MSA) of the home address			
Reference: In an MSA of less than 250,000			
Not in an MSA	0.011	0.002	0.014
	(0.040)	(0.009)	(0.021)
In an MSA of 250,000 – 499,999	-0.014	0.013	0.032
	(0.041)	(0.010)	(0.022)
In an MSA of 500,000 – 999,999	0.033	-0.007	0.050+
	(0.050)	(0.010)	(0.027)
In an MSA of 1,000,000 – 2,999,999	0.032	-0.012	0.045+
	(0.048)	(0.010)	(0.025)
In an MSA of 3 million or more	0.039	-0.048***	0.137***
	(0.042)	(0.009)	(0.022)
Not in an MSA ×2017	0.018		0.047+
	(0.047)		(0.024)
In an MSA of 250,000 – 499,999 × 2017	0.144**		0.041
	(0.049)		(0.027)
In an MSA of 500,000 – 999,999 ×2017	0.044		0.012
	(0.056)		(0.030)
In an MSA of 1,000,000 –2,999,999 × 2017	0.102+		0.068*
	(0.054)		(0.028)
In an MSA of 3 million or more × 2017	0.089+		0.015
	(0.048)		(0.025)
Health			
Having health conditions resulting in giving up driving	-0.795***	-0.454***	0.013
	(0.058)	(0.029)	(0.034)
Having health conditions resulting in asking others for help	-0.150***	-0.047**	-0.072***
	(0.035)	(0.016)	(0.019)
Travel day			
Reference: weekend			
Weekday	-0.470***	-0.118***	-0.124***
	(0.014)	(0.007)	(0.008)
Constant	2.409***	1.005***	2.102***
	-0.058	-0.025	-0.031
Observations	79,946	79,946	66,850

R^2			0.047
Adjusted R^2			0.047
Log Likelihood	-143,611.40	-178,413.40	
AIC		356,900.80	

Notes: +p<0.1, ***p<0.05, **p<0.01,*p<0.001. Values in parentheses are the standard errors.

Appendix B: Appendix for Chapter 3

Descriptive Statistics of the Samples

Table A-1 Descriptive statistics of samples for those who live alone (n=27,675) and those who do not live alone (n=46,388)

	Householders living alone		**Households not living alone**	
	Cases/Mean	Percentage/Standard deviation	Cases/Mean	Percentage/Standard deviation
Average household size			2.28	0.63
Having no car	3,017	0.11	779	0.02
Urban areas	785	0.03	249	0.005
Suburbs	462	0.02	102	0.002
Secondary cities	943	0.03	190	0.004
Rural areas and towns	827	0.03	201	0.004
Having at least one car	24,658	0.89		
Urban areas	2,600	0.09		
Suburbs	5,261	0.19		
Secondary cities	5,345	0.19		
Towns and rural areas	11,452	0.41		
Having one car			5,383	0.14
Urban areas			989	0.02
Suburbs			1,434	0.03
Secondary cities			1,529	0.03
Towns and rural areas			3,005	0.06
Having two are more cars			45,274	0.84
Urban areas			2,755	0.06
Suburbs			8,025	0.17
Secondary cities			6,223	0.13
Towns and rural areas			21,686	0.47
Household head age				
55–64	9,612	0.35	20,755	0.45
65–74	10,017	0.36	17,288	0.37
75 and older	8,046	0.29	8,345	0.18
Sex				
Male	9,940	0.36		
Female	17,735	0.64		

	Householders living alone		Households not living alone	
	Cases/Mean	Percentage/Standard deviation	Cases/Mean	Percentage/Standard deviation
Race				
African Americans	2,672	0.10	2,684	0.06
Not African Americans	25,003	0.90	43,704	0.94
Hispanic origin				
Yes	1,235	0.04	2,623	0.06
No	26,440	0.96	43,765	0.94
Household income				
Income (thousand dollars)	42.25	34.54	75.78	48.45
Income weighted by household size (thousand dollars)	42.25	34.54	51.10	32.98
Employment status				
The head and the partner (if any) not employed	19,145	0.69	19,487	0.42
Other cases	8,530	0.31	26,901	0.58
Marital status				
Married			39,820	0.86
Unmarried			6,568	0.14
Number of drivers: Having at least two drivers at home				
Yes			46,049	0.89
No			5,937	0.11
Household structure				
Living with children under 16				
Yes			2,472	0.05
No			49,514	0.95
Living with children over 16				
Yes			8,623	0.17
No			43,363	0.83

More Details about the Urban Indicator

As shown in Figure A-1, urban neighborhoods where households headed by 55 and over live had the highest residential density among four types of residential locations, with nearly half of the places having more than 100,000 persons per square mile. In contrast, around 90% of those living in rural areas and towns neighborhoods had fewer than 2,000 persons per square mile. Densities in the suburbs and secondary cities varied based on the neighborhood locations, but those who lived in the suburbs, on average, had lower population densities.

Trip data in NHTS further show that the urban indicator is an ideal proxy of car dependence measured by vehicle travel intensity, such as trip frequency, distance, and share of vehicle trips in all daily trips. As shown in Table A-2, individuals aged 55 and older who lived in urban areas only made 68% of their daily trips by vehicle. Their personal VMT on the travel day was also the lowest at 20.9 miles. Those who lived in towns and rural areas depended on vehicles the most, with 92% of the daily trips made by private vehicles. Suburbs and secondary cities were also very car-dependent. Although their residential densities are much higher than towns and rural areas, nearly 90% of daily trips were vehicle trips, and VMT per day in these areas was much higher than in urban areas.

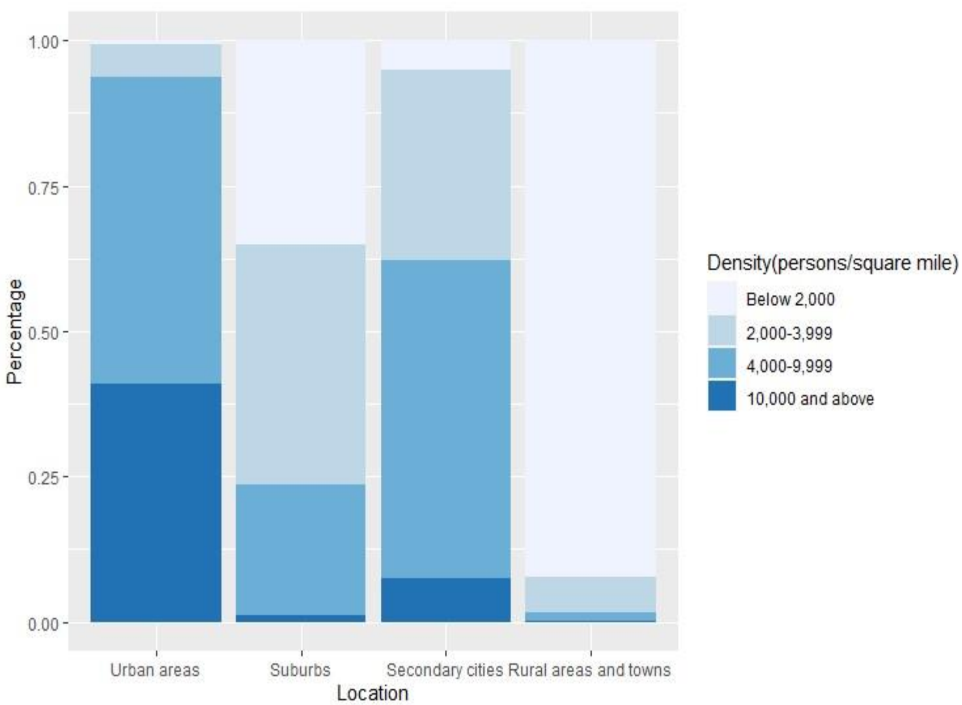

Figure A-1 *Block-group-level population density at the home location (unit: persons per square mile) for households headed by those aged 55 and over living in different locations*
Data source: *2017 NHTS*
Notes: *Values are not weighted.*

Table A-2 Vehicle travel characteristics and population density of individuals aged 55 and over in the NHTS 2017 (n=144,685)

Variable	**Urban areas**	**Suburbs**	**Secondary Cities**	**Rural areas and towns**
Daily vehicle trips	2.86	3.88	3.72	3.89
Share of vehicle trips as shares of total daily trips	0.68	0.89	0.86	0.92
Personal vehicle miles traveled on the travel day (miles)	20.91	32.31	28.35	42.95

Notes: All the above values in the table were weighted based on the personal weight. Due to car-sharing activities in many households, especially those with all members retired, having one vehicle may not mean "insufficiency" for household members who live with others. However, having two and more vehicles exceeds the daily travel need for those who live in urban areas. In contrast, regardless of the household size, living in non-urban areas without a single car can cause daily travel difficulties.

Model Selections

The purpose of this study is to jointly model residential location and vehicle ownership among older people. The traditional multinomial logit model on vehicle ownership at a given time using the built environment factors as predictors (Blumenberg et al., 2021; Caulfield, 2012; Potoglou & Kanaroglou, 2008; Zegras, 2010) have at least two methodological limitations. First, the multinomial logit model holds that unobserved factors of alternatives are independent (Train, 2009). However, the unobserved factors related to vehicle ownership and residential location are correlated. Additionally, the traditional multinomial logit model cannot capture the self-selection of residential and travel decisions (Guan et al., 2020; Mokhtarian & Cao, 2008) unless the residential and travel attitude variables are included.

A joint discrete choice model where residential location and vehicle ownership are both included as outcome variables is a commonly used way to overcome these two methodological limitations. Some other studies use longitudinal data to account for the state dependence (Clark et al., 2016; Woldeamanuel et al., 2009). For those using cross-sectional data, joint models take logit or probit forms. As an early attempt, Weinberger & Goetzke (2010) used the 2000 Census microdata to predict the probability of a joint decision on whether to live in a principal city and how many cars to own in six large U.S. metropolitan areas using a multinomial probit model.

Some other studies have used nested logit models (Salon, 2009) or cross-nested logit models (Hess et al., 2012; S. H. Kim et al., 2020; Yang et al., 2013) to model joint decisions. Both in the Generalized Extreme Value (GEV) family, these models are used to allow for correlations across alternatives by modeling unobserved utility jointly as an extreme value (Train, 2009).

A more flexible way to model the joint decisions is the mixed logit model, which can be rewritten as almost any logit model, including the nested model discussed above, under the random utility maximization (McFadden & Train, 2000). Guerra (2015) predicted the probability of vehicle ownership level and the living area based on ring roads of Mexico City using a mixed logit model with random error components denoting the residential location and vehicle ownership levels. Mixed logit models are also recently applied in transportation studies on the joint decisions of residential locations, workplace locations, and commuting mode choice (Guo et al., 2020).

Bhat and his colleague (Bhat & Guo, 2007) adopted another different approach. They did not model residential location and vehicle ownership as a joint decision. Instead, they model the residential location and vehicle ownership decisions separately, controlling for the residential sorting effect in the vehicle ownership model.

Like Guerra (2015), the alternatives in this study are only between 10 to 20. For the similar reasons discussed in his paper and make the results better communicate with planners, I followed Guerra (2015) in the model specification. Every household selects a combination of residential location and vehicle ownership level with the maximum random utility among all alternatives.

The utility function for every household *h* living in residential location *r* and have the vehicle ownership decision *v* is specified as:

$$U_{rvh}=\alpha_{rv} +\beta_r X+ \beta_v Y+\sigma_{rh}+\sigma_{vh}+\varepsilon_{rvh} \quad (1)$$

In the utility function above, U_{rvh} denotes the utility for household *i* living in the residential area *r* and owns a vehicle ownership level of *v*. The alternative specific constant is indicated by α_{rv}. The two random error terms, σ_{rh} and σ_{vh} for residential location *r* and vehicle ownership level *v*, respectively, are centered at 0 and conform to normal distribution. X and Y stand for the variables related to residential location and vehicle ownership, respectively. X and Y are different in models for household members who lived alone and those who did not. In models for those who did not live alone, I only included the variables denoting the household structure in Y but not in X to simplify the models. β_r and β_v denote the estimated fixed parameters for people living in a specific location *r* and has the vehicle ownership level *v*. ε_{rvh} is the independent and identically distributed extreme value.

In function (1), the summation of two random error components σ_r and σ_v, together with the extreme value ε_{rv}, capture the unobserved utility. Therefore, the fixed coefficients in vectors β_r and β_v show the correlations between different factors and the residential location and vehicle ownership choices after controlling unobserved correlations.

I fitted all the models with 1,500 Halton draws using Biogeme 3.2.6 (Bierlaire 2018) using Python in Jupyter Notebook 6.3.0.

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Regression Results

Table A-3 Mixed logit model results for all samples

Variable name	Living alone			Not living alone		
	Coefficient	**Robust standard error**	**Robust P-value**	**Coefficient**	**Robust standard error**	**Robust P-value**
Household head age (Reference: 55–64)						
65–74						
Car ownership (Reference: Having no car)						
Having at least one car	0.426	0.053	<0.001			
Having one car				0.123	0.108	0.255
Having two or more cars				-0.030	0.108	0.779
Residential location (Reference: Living in urban areas)						
Secondary cities	-0.158	0.053	0.003	-0.053	0.046	0.246
Suburbs	-0.125	0.055	0.023	-0.020	0.044	0.661
Rural areas and towns	-0.084	0.050	0.096	-0.083	0.041	0.043
75 and older						
Car ownership (Reference: Having no car)						
Having at least one car	0.191	0.054	<0.001			
Having one car				0.359	0.117	0.002
Having two or more cars				-0.144	0.118	0.222
Residential location (Reference: Living in urban areas)						
Secondary cities	-0.075	0.062	0.226	0.037	0.063	0.563
Suburbs	0.155	0.063	0.014	0.212	0.062	0.001
Rural areas and towns	0.052	0.058	0.370	0.001	0.058	0.985
Sex for those who live alone (Reference: males)						
Car ownership (Reference: Having no car)						
Having at least one car	-0.104	0.045	0.022			
Residential location (Reference: Living in urban areas)						
Secondary cities	0.009	0.046	0.844			
Suburbs	0.125	0.047	0.007			
Rural areas and towns	-0.089	0.043	0.036			
Race=African Americans (Reference: not African Americans)						
Car ownership (Reference: Having no car)						

Having at least one car	-0.881	0.055	<0.001			
Having one car				-0.743	0.115	<0.001
Having two or more cars				-1.110	0.118	<0.001
Residential location (Reference: Living in urban areas)						
Secondary cities	-0.421	0.066	<0.001	-0.028	0.076	0.711
Suburbs	-0.289	0.069	<0.001	-0.088	0.076	0.245
Rural areas and towns	-0.897	0.064	<0.001	-0.615	0.071	<0.001
Hispanic origin=Yes (Reference: No)						
Car ownership (Reference: Having no car)						
Having at least one car	-0.331	0.082	<0.001			
Having one car				-0.268	0.137	0.051
Having two or more cars				-0.315	0.136	0.020
Residential location (Reference: Living in urban areas)						
Secondary cities	-0.950	0.081	<0.001	-0.962	0.063	<0.001
Suburbs	-1.040	0.087	<0.001	-0.981	0.062	<0.001
Rural areas and towns	-1.880	0.087	<0.001	-1.850	0.058	<0.001
Annual household income						
Car ownership (Reference: Having no car)						
Having at least one car	1.530	0.042	<0.001			
Having one car				0.460	0.070	<0.001
Having two or more cars				0.787	0.070	<0.001
Residential location (Reference: Living in urban areas)						
Secondary cities	-0.450	0.034	<0.001	-0.119	0.030	<0.001
Suburbs	-0.080	0.035	0.021	0.188	0.030	<0.001
Rural areas and towns	-0.585	0.032	<0.001	-0.337	0.027	<0.001
Employment status=Not employed (Reference: At least one of the head and the partner (if any) is employed)						
Car ownership (Reference: Having no car)						
Having at least one car	-0.993	0.066	<0.001			
Having one car				-0.376	0.107	<0.001
Having two or more cars				-1.110	0.106	<0.001
Residential location (Reference: Living in urban areas)						
Secondary cities	-0.016	0.054	0.767	0.336	0.048	<0.001

Suburbs	0.155	0.055	0.005	0.389	0.046	<0.001
Rural areas and towns	0.219	0.050	<0.001	0.684	0.043	<0.001
Marital status=Married (Reference: Unmarried)						
Car ownership (Reference: Having no car)						
Having one car				0.337	0.110	0.002
Having two or more cars				0.871	0.110	<0.001
Household structure						
Living with children under 16=Yes (Reference: No)						
Car ownership (Reference: Having no car)						
Having one car				0.016	0.145	0.912
Having two or more cars				-0.101	0.147	0.492
Living with children over 16=Yes (Reference: No)						
Car ownership (Reference: Having no car)						
Having one car				-0.428	0.113	<0.001
Having two or more cars				-0.270	0.112	0.016
Having at least two drivers at home=Yes (Reference: No)						
Having one car				0.858	0.100	<0.001
Having two or more cars				3.040	0.097	<0.001
Random error components						
Car ownership (Reference: Having no car)						
Having at least one car	0.997	0.003	<0.001			
Having one car				0.997	0.002	<0.001
Having two or more cars				1.000	0.003	<0.001
Residential location (Reference: Living in urban areas)						
Secondary cities	0.995	0.012	<0.001	0.997	0.002	<0.001
Suburbs	1.000	0.062	<0.001	0.997	0.002	<0.001
Rural areas and towns	0.999	0.005	<0.001	1.000	0.002	<0.001
Number of observations	27,675			46,388		
Number of draws	1,500					
Rho-square	0.268			0.412		
Initial log-likelihood	-57,548.5			-115,269.8		
Final log-likelihood	-42,085.9			-67,691.7		

Table A-4 Mixed logit model on residential location and vehicle ownership decisions among households headed by those aged 55 and over and living alone

Variable name	**Coefficients**		
	55–64	65–74	75 and older
Sex (Reference: Male)			
Car ownership (Reference: Having no car)			
Having at least one car	0.039	-0.149	-0.454***
	(0.075)	(0.084)	(0.088)
Residential location (Reference: Urban areas)			
Secondary cities	0.074	-0.102	0.081
	(0.072)	(0.076)	(0.095)
Suburbs	0.117	0.150	0.236*
	(0.076)	(0.079)	(0.094)
Rural areas and towns	-0.054	-0.177*	-0.066
	(0.068)	(0.070)	(0.086)
Race and ethnicity			
African American (Reference: Not African American)			
Car ownership (Reference: Having no car)			
Having at least one car	-1.030***	-1.050***	-0.558***
	(0.086)	(0.096)	(0.120)
Residential location (Reference: Living in urban areas)			
Secondary cities	-0.434***	-0.244*	-0.23
	(0.097)	(0.113)	(0.165)
Suburbs	-0.238*	-0.098	-0.220
	(0.102)	(0.119)	(0.169)
Rural areas and towns	-0.954***	-0.709***	-0.790***
	(0.095)	(0.110)	(0.157)
Hispanic origin=Yes (Reference: No)			
Car ownership (Reference: Having no car)			
Having at least one car	-0.625***	-0.694***	-0.522***
	(0.126)	(0.133)	(0.151)
Residential location (Reference: Urban areas)			
Secondary cities	-0.831***	-0.920***	-0.770***
	(0.121)	(0.144)	(0.178)
Suburbs	-0.914***	-0.864***	-0.910***
	(0.135)	(0.153)	(0.185)
Rural areas and towns	-1.670***	-1.530***	-2.020***
	(0.127)	(0.139)	(0.194)
Logarithm of annual household income			
Car ownership (Reference: Having no car)			
Having at least one car	1.380***	1.460***	1.230***
	(0.062)	(0.072)	(0.076)
Residential location (Reference: Urban areas)			
Secondary cities	-0.309***	-0.322***	-0.215**
	(0.054)	(0.054)	(0.071)

Suburbs	0.051	0.033	0.134
	(0.056)	(0.056)	(0.070)
Rural areas and towns	-0.513***	-0.514***	-0.477***
	(0.052)	(0.050)	(0.066)
Employment status=Not employed (Reference: Being employed)			
Car ownership (Reference: Having no car)			
Having at least one car	-1.260***	-1.150***	-1.460***
	(0.091)	(0.168)	(0.253)
Residential location (Reference: Urban areas)			
Secondary cities	0.077	0.102	0.305*
	(0.084)	(0.085)	(0.146)
Suburbs	0.192	0.219*	0.428**
	(0.087)	(0.086)	(0.144)
Rural areas and towns	0.247***	0.157*	0.434***
	(0.079)	(0.077)	(0.127)
Random error terms			
Car ownership (Reference: Having no car)			
Having at least one car	0.998***	0.999***	0.993***
	(0.002)	(0.004)	(0.022)
Residential location (Reference: Living in urban areas)			
Secondary cities	0.992***	1.000***	1.010***
	(0.007)	(0.011)	(0.007)
Suburbs	1.000***	1.000***	1.000***
	(0.005)	(0.007)	(0.022)
Rural areas and towns	1.000***	0.999***	0.998***
	(0.005)	(0.008)	(0.021)
Number of observations	9,612	10,017	8,046
Number of draws	1,500	1,500	1,500
Rho-square	0.264	0.284	0.254
Initial log-likelihood	-19,987.59	-20,829.77	-16,731.19
Final log-likelihood	-14,673.41	-14,918.53	-12,478.18

Notes: ***p<0.05, **p<0.01, *p<0.001 for Robust P-values. Values in parentheses are the robust standard errors.

Table A-5 Mixed logit model on residential location and vehicle ownership decisions among households headed by those aged 55 and over and not living alone

Variable name	**Coefficients**		
	55–64	65–74	75 and older
Race=African Americans (Reference: Not African Americans)			
Car ownership (Reference: Having no car)			
Having one car	-0.993***	-0.897***	-0.975***
	(0.152)	(0.206)	(0.286)
Having two or more cars	-1.490***	-1.080***	-1.090***
	(0.160)	(0.210)	(0.294)
Residential location (Reference: Living in urban areas)			

Secondary cities	-0.092	-0.108	-0.102
	(0.099)	(0.132)	(0.208)
Suburbs	-0.247*	0.0242	-0.226
	(0.102)	(0.130)	(0.208)
Rural areas and towns	-0.741***	-0.726***	-0.797***
	(0.094)	(0.126)	(0.196)
Hispanic origin=Yes (Reference: No)			
Car ownership (Reference: Having no car)			
Having one car	-0.361	-0.275	-0.443
	(0.205)	(0.253)	(0.292)
Having two or more cars	-0.320	-0.317	-0.589*
	(0.207)	(0.253)	(0.297)
Residential location (Reference: Living in urban areas)			
Secondary cities	-0.807***	-1.250***	-1.100***
	(0.083)	(0.108)	(0.175)
Suburbs	-0.868***	-1.180***	-1.090***
	(0.082)	(0.103)	(0.168)
Rural areas and towns	-1.880***	-2.210***	-2.030***
	(0.083)	(0.103)	(0.170)
Logarithm of annual household income			
Car ownership (Reference: Having no car)			
Having one car	0.487***	0.442***	0.638***
	(0.107)	(0.137)	(0.154)
Having two or more cars	1.040***	0.932***	0.971***
	(0.107)	(0.137)	(0.154)
Residential location (Reference: Living in urban areas)			
Secondary cities	-0.199***	-0.152***	-0.149*
	(0.044)	(0.053)	(0.073)
Suburbs	0.182***	0.226***	0.173*
	(0.045)	(0.053)	(0.072)
Rural areas and towns	-0.299***	-0.366***	-0.386***
	(0.041)	(0.049)	(0.067)
Employment status=Not employed (Reference: At least one of the head and the partner (if any) is employed)			
Car ownership (Reference: Having no car)			
Having one car	-0.814***	-0.525*	-0.425
	(0.146)	(0.224)	(0.316)
Having two or more cars	-1.36***	-1.14***	-1.32***
	(0.149)	(0.223)	(0.315)
Residential location (Reference: Living in urban areas)			
Secondary cities	0.183*	0.263***	0.253*
	(0.085)	(0.068)	(0.107)
Suburbs	0.235***	0.309***	0.311***
	(0.085)	(0.067)	(0.103)

Rural areas and towns	0.576***	0.644***	0.692***
	(0.077)	(0.062)	(0.096)
Marital status=Married (Reference: Unmarried)			
Car ownership (Reference: Having no car)			
Having one car	0.022	0.576**	0.261
	(0.145)	(0.205)	(0.269)
Having two or more cars	0.584***	0.977***	0.562*
	(0.147)	(0.206)	(0.273)
Household Structure			
Living with children under 16=Yes (Reference: No)			
Car ownership (Reference: Having no car)			
Having one car	0.048	0.041	-0.085
	(0.186)	(0.255)	(0.484)
Having two or more cars	-0.018	0.122	0.161
	(0.197)	(0.256)	(0.471)
Living with children over 16=Yes (Reference: No)			
Car ownership (Reference: Having no car)			
Having one car	-0.600***	-0.370	-0.605*
	(0.157)	(0.217)	(0.289)
Having two or more cars	-0.521***	-0.222	-0.114
	(0.158)	(0.217)	(0.290)
Having at least two drivers at home=Yes (Reference: No)			
Car ownership (Reference: Having no car)			
Having one car	1.000***	1.250***	1.510***
	(0.178)	(0.208)	(0.249)
Having two or more cars	3.550***	3.490***	3.350***
	(0.173)	(0.205)	(0.248)
Random error components			
Car ownership (Reference: Having no car)			
Having one car	1.030***	1.010***	1.010***
	(0.037)	(0.004)	(0.025)
Having two or more cars	0.973***	0.995***	0.996***
	(0.029)	(0.005)	(0.018)
Residential location (Reference: Living in urban areas)			
Secondary cities	1.020***	1.000***	1.000***
	(0.146)	(0.011)	(0.056)
Suburbs	1.010***	1.010***	1.010***
	(0.074)	(0.009)	(0.027)
Rural areas and towns	0.970***	0.996***	0.984***
	(0.063)	(0.005)	(0.029)
Number of observations	20755	17288	8345
Number of draws	1500	1500	1500
Rho-square	0.427	0.428	0.35

Initial log-likelihood	-51574.24	-42959.07	-20736.55
Final log-likelihood	-29485.83	-24535.35	-13425.57

Notes: ***p<0.05, **p<0.01, *p<0.001 for Robust P-values. Values in parentheses are the robust standard errors.

Appendix C: Appendix for Chapter 4

Selection of out-of-home and online activities

I selected technology activities that have replacements or supplementary formats in the real world for the following purposes: work-related, shopping, dining out, social activities, healthcare, buying services, and transportation technologies. As for the out-of-home travel, consistent with categories of 2017 NHTS (Federal Highway Administration, 2019), I selected out-of-home activities that can be replaced or supplemented by the online activities. I used family activities, recreational activities, religious and volunteer activities as proxies of social activities. As shown in Table 4.2, all out-of-home activities are calculated by summing up all activities mentioned above and exercise activities. Technology usage might squeeze older adults' time for outdoor exercise or motivate them to exercise more. Transportation technologies can influence all out-of-home activities. I did not include other activities which take small shares of older adults' daily travel, such as childcare trips.

Table A-1 shows the frequency of technology usage among older adults. Table A-2 shows the frequency of vehicle travel for different older adults among the samples in the survey.

Table A-1 Frequency of technology usage among older adults

	Never	Less than once a month	Less than once a week, but more than once a month	At least once a week but less than daily	Daily
Having video/voice calls using FaceTime, Zoom, or other software for business/work reasons	64.79	15.58	7.93	8.09	6.10
Shopping online (not including meals)	16.18	29.12	29.96	20.48	6.73
E-health					
Emailing or asking a question to a health professional online	58.41	25.98	8.37	5.18	4.54
Getting prescriptions for medicine online	53.19	27.37	13.23	5.26	3.43
Scheduling a restaurant or food delivery online	58.76	19.00	13.23	9.56	1.91
Social activities					
Using social media (e.g., Facebook, Instagram, and Twitter)	24.78	6.10	6.02	15.02	50.56

Having video/voice calls using FaceTime, Zoom, or other software with friends/family	48.65	21.31	13.59	13.27	5.66
Transportation technologies					
Using Google Maps or other mapping/planning apps to check an address/traffic/routes or plan an out-of-home trip	23.19	30.16	23.35	18.84	6.93
Using smartphone apps to hail an Uber/Lyft/other on-demand transportation services	80.40	10.36	5.62	3.35	2.75
Appointment services and online banking					
Making an appointment with a healthcare provider online	49.12	32.75	12.47	4.90	3.23
Making an appointment online with a service provider (e.g., barbershop, pet care)	52.31	26.25	15.86	5.54	2.51
Using an online bank or other transactional applications (e.g., PayPal and Venmo) to complete financial transactions	30.44	14.70	21.67	24.74	10.92

Table A-2 Frequency of vehicle travel for different purposes among older adults

	Never	Less than once a month	Less than once a week, but more than once a month	Once or twice per week	More than twice per week
Work or work-related	68.57	4.94	3.19	5.78	20.00
Shop for food or durable goods (groceries, clothes, appliances, gas)	6.02	6.25	21.35	48.41	20.44
Health care visit (medical, dental, therapy)	9.76	58.29	21.55	7.29	5.58
Buy meals (go out for a meal, snacks or drinks, carry-out)	13.31	16.41	24.38	32.47	15.90
Social activities					
Visit family or friends	10.80	22.39	27.41	28.96	12.91
Religious or other community/volunteering activities	41.79	15.98	11.20	24.82	8.69
Recreational activities (visit parks, movies, bars, museums)	31.20	28.01	20.12	14.82	8.33
Buy services or other errands (e.g., dry cleaners, banking, service a car, pet	13.67	21.83	26.77	27.05	13.15

care, haircut, going to the post office or library)					
Exercise (go for a jog, walk, walk the dog, go to the gym)	33.75	10.20	10.72	19.08	28.73

Principal factor analysis

Based on the Technology Acceptance Model (Davis, 1989), I asked the respondents to select from "totally disagree" to "totally agree" (scored from 1-5) in a series of questions related to the technology usage difficulties, acceptance, and resistance among older adults. I used the Principal Factor Analysis (PCA) to select the common factor of the difficulties of conducting the following activities online: making phone calls, sending or receiving emails, sending or receiving text messages, checking social media apps, online shopping, visiting websites for daily news or entertainment, using Google or other engines to do some research or find helpful information, attending online classes or webinars, and making appointments online. The factor loadings of these factors are consistently positive and close to 0.6 and explain 66.5% of the variance. Table A-3 shows the PCA results.

Table A-3 Principal factor analysis for attitudes and perceptions towards Internet and technology

Item	Factor 1_Loadings	Factor 2_Loadings
I trust people whom I know in the real world more than those I know in the virtual world.		0.73
The online transaction with my credit/debit card is not safe.		0.77
Having Wi-Fi and/or 3G/4G connectivity everywhere I go is essential to me.	0.81	
I get a lot more news about current events from social media and cable TV than from traditional sources like broadcast TV and newspapers.	0.81	

Notes: Loadings less than 0.30 were suppressed. Two factors contribute to 62.8% of the total variance.

To measure residential and travel preferences, I have asked the respondents to select from "totally disagree" to "totally agree" for the questions listed in Table A-4. The measurements come from the questions selected from past studies (Circella et al., 2016; Handy et al., 2005, 2006).

Table A-4 Principal factor analysis for residential and travel attitudes

Item	**Factor 1_Loadings**	**Factor 2_Loadings**	**Factor 3_Loadings**
It is inconvenient to travel without a car.	0.76		0.40
I need a car for daily routines.	0.80		
I am committed to using a less polluting means of transportation as much as possible.		0.92	0.37
I prefer to live in a spacious home, even if it is farther from public transportation and many places I go to.	0.58	0.41	-0.69

Notes: Loadings less than 0.30 were suppressed. Three factors contribute to 85.3% of the total variance.

Transformations for the examination of travel and ICT

I transformed the outcome variables for specific models. Table A-5 demonstrates a summary of the outcome variable transformations. As shown in Table A-2, the distributions of all outcomes except for commuting are close to normal distribution if they are treated as interval variables. Nevertheless, for technology usage, while some variables in Table A-1 are close to the normal distribution, many other variables, such as those related to e-health usage and ride-hailing usage, are biased towards those who have never used these technologies. In contrast, more than half of respondents had used social media daily. I treat variables as interval variables as Cao (2012) when the choices' distributions are close to normal distribution. I transformed the variables with most samples having never used the services or having used the services daily into dummy variables denoting whether the respondent had used the service before.

Table A-5 A summary of outcome variable transformations

Purpose	**Technology usage**	**Out-of-home activities**	**Transformations**
Total	All technology usages	All trip purposes listed below	Technology usage: The logarithm term of all relevant activities plus 1
Work-related	Having video/voice calls using FaceTime, Zoom, or other software for business/work reasons	Work or work-related	Dropped
Shopping	Shopping online (not including meals)	Shop for food or durable goods (groceries, clothes, appliances, gas)	No transformations
Dining out	Scheduling a restaurant or food delivery online	Buy meals (go out for a meal, snacks or drinks, carry-out)	Technology usage as a dummy variable to denote whether the

			respondent has used this application before
Social activities	Using social media (e.g., Facebook, Instagram, and Twitter)	Visit family or friends	Different models for social media and Zoom usage. Social media usage to a dummy: whether to use daily; Zoom usage to a dummy: whether the respondent used this application before. Social trips transformed to the logarithm term of all relevant activities plus 1
	Having video/voice calls using FaceTime, Zoom, or other software with friends/family	Religious or other community/volunteering activities	
		Recreational activities (visit parks, movies, bars, museums)	
Healthcare	Emailing or asking a question to a health professional online	Health care visit (medical, dental, therapy)	Health-related technologies to a dummy variable: whether the respondent used either application before
	Getting prescriptions for medicine online		
Buying services	Making an appointment online with a service provider (e.g., barbershop, pet care)	Buy services or other errands (e.g., dry cleaners, banking, service a car, pet care, haircut, going to the post office or library)	Dropped
	Using an online bank or other transactional applications (e.g., Paypal and Venmo) to complete financial transactions		
Transportation technologies	Using Google Maps or other mapping/planning apps to check an address/traffic/routes or plan an out-of-home trip	Same as the “Total” model	No transformations
	Using smartphone apps to hail an Uber/Lyft/other on-demand transportation services		To a dummy variable: whether the respondent used this application before

Based on the relationships for different ICT activities, I decide how many models to fit for different activity purposes. I dropped the models examining the relationships between making appointments and e-bank and maintenance activities, since maintenance activities are not pure equivalents to online banking and appointment-making activities. Due to the small sample size, I also dropped the models examining the relationship between teleworking and commuting among older adults. Various e-health activities have similar relationships with healthcare visits, and therefore, I only fitted one model for e-health. Transport planning applications and ride-hailing have different roles in vehicle travel. While transport planning applications might increase vehicle travel flexibility and vehicle travel, ride-hailing services' role is less clear based on the literature. Therefore, I fitted models for these two transportation technologies separately. I also fitted different models for social media usage and having Zoom meetings with friends or family members. Finally, I fitted a model to examine the overall relationship between ICT usage frequency and daily travel.

The calculation of total travel and technology usage frequency is based on Table A-6. For the overall frequency of technology usage and travel, I added the frequencies of all activities together as continuous variables. For other models in which ICT and/or travel activities are constituted by more than one item (for example, e-health), I added values of outcome variables together and scaled the variable to a range between 1-5. The added value of ICT usage does not conform to the normal distribution, so I transform this value to the logarithm term of ICT usage frequency plus one. Similarly, I also transformed the added value of vehicle travel for social activities to the logarithm term of all relevant activities plus 1.

Table A-6 Calculation of travel and technology frequencies

Frequency	**Monthly values for calculation**
Never	0
Less than once a month	1
Less than once a week but more than once a month	2.5
Once or twice per week/At least once a week	6
More than twice a week	10
Daily	20

Finally, I transformed the annual household income into a continuous variable by selecting the midpoint of each category. Those who earned $14,999 and under and $200,000 were counted as $14,999 and $200,000 respectively for their annual incomes. As the household income has a right tail, I transformed the variable to the logarithm term of the household income divided by 1000.

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