9-2024

Understanding Travel Behavior and Accessibility for Older Adults: A Comprehensive Framework

Andy Hong
University of Utah

Cathy Liu
University of Utah

Ja Young Kim
University of Utah

Zihao Wen
University of Utah

Recommended Citation

Hong, A., Liu, X. C., Kim, J. Y., & Wen, Z. (2024). Understanding Travel Behavior and Accessibility for Older Adults: A Comprehensive Framework. NITC-RR-1503. Portland, OR: Transportation Research and Education Center (TREC). http://dx.doi.org/10.15760/trec.297

NATIONAL INSTITUTE for TRANSPORTATION and COMMUNITIES

Final Report 1503
September 2024

Photo by walencienne/iStock

Understanding Travel Behavior and Accessibility for Older Adults: A Comprehensive Framework

E-Sok Andy Hong, Ph.D.
Xiaoyue Cathy Liu, Ph.D.
Ja Young Kim
Zihao Wen

THE UNIVERSITY OF UTAH

Understanding Travel Behavior and Accessibility for Older Adults: A Comprehensive Framework

Final Report

NITC-RR-1503

by

E-Sok Andy Hong (PI)
Xiaoyue Cathy Liu (Co-PI)
Ja Young Kim
Zihao Wen

University of Utah

for

National Institute for Transportation and Communities (NITC)
P.O. Box 751
Portland, OR 97207

NATIONAL INSTITUTE for TRANSPORTATION and COMMUNITIES

September 2024

Technical Report Documentation Page

1. Report No. NITC-RR-1503	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Understanding Travel Behavior and Accessibility for Older Adults: A Comprehensive Framework		5. Report Date September 2024 6. Performing Organization Code
7. Author(s) E-Sok Andy Hong, Xiaoyue Cathy Liu, Ja Young Kim, Zihao Wen		8. Performing Organization Report No.
9. Performing Organization Name and Address National Institute for Transportation and Communities (NITC) P.O. Box 751 Portland, OR 97207		10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address U.S. Department of Transportation Office of the Assistant Secretary for Research and Technology 1200 New Jersey Avenue, SE, Washington, DC 20590		13. Type of Report and Period Covered 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

This study used a mixed-method design to examine travel behavior and accessibility of older adults. The research team conducted a statewide survey and focus groups to gather travel behavior data of older adults (50+) residing in Utah. The study also employed a two-step floating catchment area method, a novel spatial technique, and integrated the survey data to accurately measure travel accessibility of older adults. Using the survey data of 724 older adults as well as the focus group interviews of 18 older individuals, we found a significant dissatisfaction and vulnerability experienced by older adults with limited mobility. The distribution patterns of accessibility revealed communities with limited options for specific types of facilities, highlighting the need for addressing equitable access to different destinations. The study identified a positive relationship between travel frequency and satisfaction up to a certain threshold, beyond which satisfaction declined. Further investigation is needed to explore this threshold, considering health-related issues and travel fatigue. Lastly, the study emphasized the importance of considering diverse dimensions of older adults' needs and developing distinct accessibility measures for underrepresented groups, such as those with low income, disabilities, and older adults experiencing mobility limitations. The findings highlight the need for policymakers to address the critical accessibility and mobility gaps and improve travel experiences for older adults.

17. Key Words Older adults, accessibility, mobility, travel behavior, destinations		18. Distribution Statement No restrictions. Copies available from NITC: www.nitc-utc.net	
19. Security Classification (of this report) Unclassified	20. Security Classification (of this page) Unclassified	21. No. of Pages	22. Price

ACKNOWLEDGEMENTS

This project was funded by the National Institute for Transportation and Communities (NITC, grant number NITC-RR-1503), a U.S. DOT University Transportation Center. We would also like to acknowledge partial support from the University of Utah's Center on Aging (Innovations Award).

DISCLAIMER

RECOMMENDED CITATION

Hong, A., Liu, X. C., Kim, J. Y., & Wen, Z. (2024). Understanding Travel Behavior and Accessibility for Older Adults: A Comprehensive Framework. NITC-RR-1503. Portland, OR: Transportation Research and Education Center (TREC).

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

Background
Transportation and accessibility are fundamental for older adults. They directly affect an individual's ability to access essential goods, services, and maintain social connections. However, current transportation planning often fails to address the unique accessibility challenges faced by this population. Conventional practices rely on data reflecting the general population, neglecting the specific needs and limitations of older individuals.

Project Goal
This project seeks to develop a comprehensive framework that combines quantitative and qualitative approaches to understand travel behavior and accessibility of older adults. Specifically, our objectives are: 1) to examine older adults' travel behaviors and satisfaction using travel surveys tailored to older adults; 2) to understand the challenges and opportunities of transportation for older adults using qualitative methods; and 3) to develop an integrated accessibility measure that reflects older adults' mobility patterns.

Methods
<u>Survey</u>: The research team conducted a statewide survey targeting Utah residents aged 50 and above. To ensure a diverse participant pool and increase response rates, the survey was made available in both online and paper formats. The research team employed various recruitment channels, including partnerships with organizations. A total of 830 participants completed the survey. Due to ineligibility, missing information, or incomprehension, the final sample consisted of 724 individuals.

<u>Focus groups</u>: To gain deeper insights into older adults' transportation behaviors and experiences, the research team also conducted focus group interviews with 18 older adults from Salt Lake County, Weber County, and Box Elder County. The interviews were audio-recorded with participant consent, transcribed using pseudonyms, and analyzed using the MAXQDA 2022 software. We employed an inductive approach to create initial codes and identified themes through collaborative work, constantly reviewing and modifying them.

<u>Accessibility calculation</u>: This research used the two-step floating catchment area (2SFCA) method for assessing the accessibility of a population within a specific area. It involved two main steps: first, creating catchment areas around supply points based on a predefined travel time threshold and calculating the supply-to-demand ratio; second, generating catchment areas around demand points and aggregating the supply-to-demand ratios from nearby supply points. Various distance decay functions, including inverse-power, exponential, Gaussian, and kernel density models, were employed to estimate accessibility. The study specifically focused on vehicle trips and examined the relationship between travel time, distance, and income. Lastly, survey data was used to calibrate and refine accessibility scores.

Results and Discussion

Survey results: The survey participants were distributed across various age groups, with the majority falling within the 60- to 79-year-old range. Urban and rural areas had differences in race distribution, household income, and the use of mobility aids. Social activities and shopping were the most common activities among participants. Regression models revealed that high-income individuals and those with better health exhibited higher travel frequency. Urban residence was associated with shorter travel time and distance. Travel satisfaction was influenced by age, income, urban residence, health status, and the use of assistive devices. There was a nonlinear relationship between travel frequency and travel satisfaction, with satisfaction declining beyond a certain threshold. Social activities had a positive relationship with travel satisfaction, particularly in rural areas. The study highlights the heterogeneity of older adults and emphasizes the importance of considering health, nonlinear relationships, and urban/rural differences in travel behavior and satisfaction. Improving accessibility to social and cultural destinations in rural areas is crucial for older adults' well-being.

Focus group results: There was a wide spectrum of travel behaviors among older adults, highlighting the influence of social and personal factors on their current modal choices. Older adults' desire for independence remained strong, but their mode preferences varied based on their day-to-day patterns. Four modal groups were identified based on participants' level of multimodal behavior: super single modal, semi single modal, semi multimodal, and super multimodal. Each group had different preferences and tendencies regarding their transportation choices. Single-modal groups were attached to cars, while multimodal groups showed greater adaptability to different modes. Future transportation behavior varied, with some individuals intending to decrease travel frequencies or stay home when they can no longer drive, while others were open to alternative mode choices. The study also identified three dimensions related to transportation resources: personal, social, and physical. Personal factors such as physical health, preferences, financial constraints, and convenience influenced transportation choices. Social factors, including social networks and family support, played a role in older adults' travel decisions. The physical dimension encompassed the perception of the environment and the actual availability of transportation resources. Positive experiences and perceptions of public transit were more likely to encourage its use, while negative perceptions and limited resources hindered its adoption. Additionally, the study emphasized the impact of the built environment on travel behavior. Neighborhood walkability and access to public transit influenced individuals' mode choices. However, individual perceptions, motivations, and personal needs were also significant factors in determining travel preferences.

Accessibility results: The study utilized an adjusted 2SFCA method with a decay function incorporating time and cost (TC 2SFCA) to examine accessibility to various services for older adults. The results revealed differences in accessibility based on spatial distribution, with higher accessibility in certain regions and lower accessibility in the eastern and western suburbs. The TC 2SFCA method was compared to Gaussian 2SFCA and showed consistent results while overcoming overestimation issues. The study also considered the setting of catchment areas and demonstrated that a 30-minute threshold travel time provided high accessibility in Salt Lake County. Integrated accessibility analysis highlighted the availability of resources per person, considering demand, supply, and trip frequency. Survey data integration showed increased accessibility for religion and recreation and decreased accessibility for shopping. The study emphasized the suitability of the TC 2SFCA method for measuring accessibility for older adults and the importance of neighborhood accessibility. However, it acknowledged that the results were based on a sample of relatively healthy older adults who still drive, and that specific populations with different needs require further attention.

Conclusion

The study explored travel behaviors of older individuals, finding that community-dwelling older adults with limited mobility expressed significant dissatisfaction with their travel experiences. Our findings highlight complex relationships between travel behavior and satisfaction among older adults, suggesting a nonlinear pattern with travel satisfaction. The study employed the 2SFCA method and survey data to measure travel accessibility accurately, highlighting the need to fill the accessibility gaps to ensure equitable access. It stressed the importance of considering diverse dimensions of older adults' needs and developing distinct accessibility measures for underrepresented groups. Future research should also consider the accessibility of multiple modes of travel for older adults in the post-pandemic era.

1.0 INTRODUCTION

1.1 BACKGROUND

Transportation and accessibility are fundamental for older adults. They directly influence older adults' ability to participate in daily activities, such as finding and keeping jobs, attending schools, obtaining goods and services, and interacting with others. Even in the absence of mobility limitations, a system that prioritizes accessibility for those with mobility issues will offer significant advantages for all members of society by promoting social interactions and reducing social isolation. Enhancing the accessibility of the entire system for those encountering specific obstacles would result in improved accessibility for general users as well. For example, wheelchair ramps or curb cuts are advantageous not just for those in wheelchairs but also for other users who need to travel with wheeled items, such as bicycles or strollers. These ramps facilitate mobility and make transportation more convenient. Similarly, pedestrian islands located at busy junctions give individuals with limited mobility more time to safely cross the intersection.

While much has been done to make the transportation system more accessible (e.g., ADA legislation), older adults increasingly face a range of challenges and barriers to completing trips in a timely, affordable, safe, and effective manner for their needs and wants. Nearly one in five older individuals have a decline in their ability to drive safely, and the loss of driving ability in later life can lead to increased isolation and a higher likelihood of developing depression (Chihuri et al., 2016). Ensuring safe and accessible transportation options for older adults, who are living longer but no longer able to drive safely, is of utmost importance. It enables them to remain connected, healthy, and engaged in their community (Foley et al., 2002). A system that may also help to alleviate transportation barriers for older adults as their transportation needs shift over time should also be helpful and accessible to the disability community, providing ample options for those who cannot drive on their own.

1.2 LITERATURE REVIEW

1.2.1 Older Adults' Travel Behavior

A growing aging population has spurred increased research on the diverse mobility challenges faced by older adults. Mobility plays a central role in promoting health and well-being (Metz, 2000; Schwanen & Páez, 2010). The consequences of limited mobility for the aging demographic include health problems from sedentary behaviors, and fewer opportunities to receive health services, spend time with their families and loved ones, and participate in social activities (Satariano et al., 2012). Older adults' travel behavior is often measured with travel frequency, non-home activity frequency, travel distance, and travel time, and it varies with socioeconomic factors, built environment, and trip characteristics (Kim & Ulfarsson, 2004). While driving is still the most preferred among older adults, they experience limitation with driving due to declining functions or mobility problems. Although older women are more likely to use modes of transportation other than cars, it is not easy to find realistic alternatives for older adults to travel independently (Jamal & Newbold, 2020; Rosenbloom, 2009) unless they live in urban areas with high density or connectivity (Moniruzzaman et al., 2013) and mixed land use (Böcker et al., 2017). The average distance traveled by older persons is shorter, and their total distance decreases as they get older (Jamal & Newbold, 2020). Recent studies pointed to the heterogeneity of older adults and the need for further research and policies for them (Shergold et al., 2015).

Driving is a critical aspect of mobility in the U.S., and there is no exception for older adults. Driving allows individuals to maintain mobility, independence, social engagement, and access to everyday activities and services. It is a major mode for both utilitarian and recreational purposes; as Coughlin (2001) states, "the ability to travel freely in the community has not only a practical meaning but also a strong emotional meaning; pursuit of daily activities, for these [older adults], is vital to their perception of being part of society." Being able to travel with their own private vehicles allows older adults to sustain their social life and access opportunities. On the other hand, aging deters older adults from driving, as their cognition and physical abilities decline with age. Ideally, public transportation could provide alternative mobility for older adults when it is reliable, convenient, accessible, and safe (Rosenbloom, 2009). For some individuals, public transportation serves as a means for significant commuting purposes, as well as for leisure activities and special occasions. Depending on numerous factors such as health, income, and accessibility, older adults optimize their travel mode. In urban areas with high-quality public transit services, older adults tend to utilize public transit more often, especially when facing financial constraints or having physical limitations for driving (Schwanen & Ziegler, 2011).

Research has shown that having more knowledge and experience in various transportation modes can make people more comfortable with their future options and, thus, be more satisfied with their mobility choices (Vivoda et al., 2018). Attachment to a particular travel mode may significantly contribute to an individual's current and future mode choices and travel behavior. Therefore, it is crucial to understand factors influencing mode attachment and design initiatives that open the potential to adopt various alternative modes for older adults.

1.2.2 Travel Behavior and Travel Satisfaction

Although travel behavior does not necessarily represent travel satisfaction, there has been an increased focus on travel experiences and satisfaction (Taniguchi et al., 2014). Studies also confirmed the expanded link between travel satisfaction and life satisfaction (Ettema et al., 2011; Lättman et al., 2019). A study found older adults are more satisfied with public transit service than young adults, while they showed less satisfaction in transit amenities and waiting places such as shelters (Ravensbergen et al., 2023), and the first- and last-mile distance also negatively affects travel satisfaction (Taniguchi et al., 2014). Social relationships and participation in activities are essential to maintaining quality of life in later years. Social participation becomes more challenging as one gets older due to functional loss and challenging environmental conditions. As a result, one's mobility in later life is a crucial component of social connections (Mollenkopf et al., 1997). A study in Hong Kong found that travel itself can be considered a form of leisure activity for older adults and increase life satisfaction (Bai et al., 2017).

1.2.3 Multimodality

Recently, there has been increasing literature focusing on multimodality, which means using more than one mode of transportation for travel within a certain period of time (Heinen & Mattioli, 2019; Kuhnimhof et al., 2012; Nobis, 2007). Previously, multimodality has been disregarded, partly due to the challenges of collecting the necessary data and building analytical models (Molin et al., 2016). While multimodal travelers are still a small fraction of the general population, multimodality is strongly associated with life stages. Young people such as Millennials or Gen X (Ralph, 2017) and older adults are more likely to be multimodal (Nobis, 2007), with possible relation to the positive correlation between multimodality and one's ability to drive, whether having a car or a driver's license (Diana & Mokhtarian, 2009; Kuhnimhof et al., 2006). Multimodal travelers also tend to be more educated and live in urban areas with better access to public transportation (Buehler & Hamre, 2015). Similar findings were found in a study focused on older adults, showing more likelihood of multimodality among those residing in neighborhoods with a higher land use mix and transit service frequency. Regarding social connections, older adults living alone were more likely to be multimodal (Ozbilen et al., 2022).

1.2.4 Ecological Models of Travel Behavior

Older adults' mobility and accessibility can be affected by multiple factors, other than transportation-related issues. A useful framework for understanding travel behavior in later life is the ecological theory of aging (Lawton & Nahemow, 1973). This framework views aging as a dynamic interaction between an individual's functional age and adaptation to their physical and social environment. Based on the theory, a Canadian study explored the determinants of travel using "autonomy components," personal characteristics, and "security components" as access to resources (Smith & Sylvestre, 2001). Ecological models are getting more attention as a better way to promote active living in public health (Sallis et al., 2006). As ways of thinking about how people interact with their physical and social environments, the levels often included intrapersonal, interpersonal/cultural, organizational, physical environment, and policy. In transportation literature, a study used an ecological model as multilevel factors affecting the travel behavior of older women and found that social environment and physical environment, as well as individual level, affect women's mobility in terms of trip frequency and destinations (Hough et al., 2008).

Older adults' personal and social dimensions influence their travel behaviors. The personal dimension includes older adults' demographic information, such as gender, marital status, race, income, education, etc., as well as some physical conditions, such as mobility limitations and health. Personal circumstances can affect older adults' attitudes and capability to use multiple modes of transportation (Nordbakke &

Schwanen, 2015). The social dimension covers a person's social capital and network. Each of these variables can affect travel behavior, frequency of use, and the types of destination that people travel to (Al-Rashid et al., 2022).

In addition to the personal and social dimensions, the physical dimension can play a considerable role in determining older adults' travel behavior. Research by Dickerson et al. (2019) emphasized that the built environment plays a significant role in making preference choices of where they live, as the environment inhibits their ability to maintain mobility, especially for those who do not drive. The built environment tends to provide opportunities for older adults to adopt different transportation modes and may affect multimodality. Ma & Cao's 2019 study confirms that the built environment affects travel behaviors through the influence on people's perceptions, as well as travel attitudes remarkably affecting the perceptions of travel behavior. The physical dimension of built environments and travel behavior are closely related, as the absence of physical infrastructures such as public transportation and accessible sidewalk designs can prevent multimodality and advocates car driving and social isolation for those who cannot drive. Understanding the physical dimension of transportation resources, especially for older adults, is crucial as they are more vulnerable to mobility limitations associated with decreased social participation, increased annual healthcare expenditures, and the risk of depression and mortality (Chudyk et al., 2015). The same study demonstrated that the number of destinations had a positive relationship with the number of walking trips of older adults, thereby increasing physical activity. For that reason, developing communities that promote older adults' mobility, independence, and well-being is indispensable to creating cities that can "age-in-place."

1.2.5 Older Adults' Accessibility

The COVID-19 pandemic has aggravated the gross inequality in older people's access to healthcare and other essential services. Many older adults have been urged to stay home because of the heightened risk of severe illness associated with age (World Health Organization, 2020). These individuals typically have limited financial resources and reduced physical and cognitive capability, with unique mobility challenges that normal healthy adults would not experience (Luiu et al., 2017). It is even more difficult for them to access necessary food and possibly medical services compared with average healthy adults (Ni et al., 2015; Wu et al., 2020). These challenges put older adults in an extremely disadvantaged position. Yet with an increasingly aging population, the resulting inconvenience should have never been neglected for older adults. Therefore, measuring older people's potential to access essential services objectively and accurately is critical for transportation planners and decision-makers to comprehensively understand their mobility needs and formulate effective policies to allocate resources to help improve their quality of life.

1.2.6 Accessibility Measurement for Older Adults

Accessibility, a core concept in transportation planning, reflects the ease of reaching destinations and engaging in activities (Levinson, 1998). However, measuring accessibility is complex. Challenges include defining factors that impede or attract travel

(Handy & Niemeier, 1997), accounting for individual variations in abilities (Miller, 2005), and the lack of standardized measures. Additionally, static accessibility measures may not capture the dynamic nature of transportation systems, and the link between accessibility and land values remains unclear, hindering evaluation of transportation investments (Boisjoly & El-Geneidy, 2016).

Previously, researchers have developed various methods to quantify accessibility, each capturing a distinct aspect of ease of access. The cumulative opportunity measure, developed by Vickerman (1974) and Wachs & Kumagai (1973), counts the number of potential opportunities (e.g., jobs, shops) that can be reached within a predetermined travel time threshold. This method emphasizes the sheer quantity of accessible options within a specific timeframe. In contrast, the gravity-based measure (Hansen, 1959) treats destinations as having a "gravitational pull" on individuals based on factors like size and attractiveness. Locations closer to these "heavy" destinations, or with more destinations nearby, are considered more accessible. Finally, utility-based measures, developed by Ben-Akiva & Lermand (1977) and Neuburger (1971), go beyond simple distance or attraction and consider individual preferences and the cost of reaching a destination. This approach provides the most nuanced understanding of accessibility, but also requires complex data collection and modeling.

For older adults, accessibility goes beyond just the number of destinations or their attractiveness. Pedestrian accessibility at the neighborhood scale plays a crucial role. A study by Gaglione et al. (2021) examined this granular approach to accessibility by measuring neighborhood walkability for older adults using factors such as sidewalk quality, street connectivity, and land-use mix. Their findings suggest that older adults living in more walkable neighborhoods tend to have better accessibility. However, this study relied on expert judgment (e.g. analytic hierarchical process) to assign weights to different accessibility features. This approach can be subjective, time-consuming, and potentially biased. Another approach considers the cumulative opportunity specifically for services frequented by older adults. Chen et al. (2020) measured accessibility to such facilities in age-restricted communities. They calculated the number of facilities reachable within a certain timeframe and normalized the accessibility score for each type of facility. However, this method assumes equal importance for all facilities and ignores potential limitations like service capacity. To account for these limitations, scholars have proposed the two-step floating catchment area (2SFCA) method to calculate accessibility. This method goes beyond simply counting available options and considers the competition for resources. For example, Chen et al. (2021) measured accessibility to healthcare services for older bus passengers based on the 2SFCA method. Guo et al. (2019) utilized the 2SFCA method to assess accessibility to urban parks for older adult residents. The 2SFCA method can account for the effect of facility service capacity and population density, providing a more realistic and accurate picture of accessibility.

While there has been significant research on measuring accessibility using various methods, a gap exists in comprehensively assessing accessibility for older adults across various destinations. Existing studies often focus on a single type of facility or rely on methods with limitations. This study aims to bridge this gap. We propose a novel approach that first calculates the accessibility of each type of facility using the 2SFCA method, applying weights based on the frequency of visits to major destinations by older adults. This weighting system addresses the limitations of assuming equal importance for all facilities. Finally, we will combine the accessibility scores for different facilities to obtain a comprehensive accessibility measurement that considers not only the number of options but also service capacity and population density.

1.2.6.1 2SFCA Method Applications

The 2SFCA method was initially proposed by Radke et al. (2000) and then developed by Luo et al. (2003). Luo et al. utilized the 2SFCA method to examine spatial accessibility to primary care in Chicago. They found that 2SFCA can identify health professional shortage areas precisely. Since then, the approach has been implemented in a myriad of studies to investigate the accessibility of various service facilities. Qin et al. (2022) sought to measure the rationality of shopping places' spatial layout in Beijing, China, based on the 2SFCA method. Dai et al. (2011) applied the method to measure the spatial access to food stores in southwest Mississippi. In order to ascertain whether older persons experience unequal park access owing to their socioeconomic status, Guo et al. (2019) estimated park access for older adults using the 2SFCA method. Hong et al. (2015) used the method to analyze the church accessibility and church shortage in the 31 provincial capital cities of China, identifying nine of them as having a dearth of churches and poor accessibility.

1.2.6.2 Decay Function Forms of 2SFCA

There has been ongoing research to expand and refine the original 2SFCA method. The incorporation of the decay function in the original 2SFCA method to account for the effect of distance decay has been the subject of numerous studies. Luo et al. (2009) proposed an enhanced 2SFCA to evaluate accessibility by allocating impedance weight to each travel time zone within a catchment area. The closer a travel time zone is to the demand point corresponds to a more significant weight. However, the segmentation of time zone and weighting are subjective. Additionally, all populations have equal access to services in each travel time zone (Dai et al., 2011). To model the distance decay effect continuously, Dai et al. presented kernel density 2SFCA (2011) and Gaussian 2SFCA (2010) by respectively introducing a kernel density function and a Gaussian function. Furthermore, Wang et al. (2013) combined the gravity model with 2SFCA (known as gravity 2SFCA) by introducing gravity-type decay functions. However, the above studies directly introduce the decay functions without thoroughly examining their applicability and limitations. Chen et al. (2019) compared the performance of 2SFCA models with different decay functions using Root Mean Square Error (RMSE). That provides the theoretical support necessary for the choice of the decay function in the 2SFCA method.

In addition, the above studies merely consider distance as the spatial impedance. Acknowledging that a myriad of variables influences people's propensity to travel, other than distance, it is important to integrate them into a modified decay function to quantify how people access opportunities, such as availability (travel time) and affordability (cost). Goodwin (1974) and Odoki et al. (2001) argue that generalized time is a more appropriate metric for spatial impedance since it evaluates the overall cost of a trip or a mode of transportation, taking into account not only non-monetary costs (travel time) but also monetary costs.

1.2.6.3 Estimation of Spatial Impedance

Travel distance estimation in previous studies was generally performed in software packages, such as ArcGIS, to obtain the shortest path from an origin to a destination. Then, travel time can be estimated from the distance and the assumed speed. Yet, in reality, travel time varies across different times of day based on traffic conditions.

In recent years, studies have attempted to retrieve travel time via an online map API service. Cheng et al. (2016) analyzed the spatial differences in the accessibility of hospitals based on travel time derived from online map API. Tao et al. (2018) also resorted to online map API to improve travel time estimation for multimodal transportation. Wang et al. (2011) developed a Google Maps API tool and compared the results with those of the ArcGIS Network Analyst module to demonstrate its advantages. Google Maps API outperformed ArcGIS Network Analyst on many fronts. Overall, API services can provide more accurate estimates of travel times.

1.2.6.4 Threshold Travel Time

The catchment area within a threshold travel time is often set based on authority guidelines (Li et al., 2021; Fransen et al., 2015; Chen et al., 2021). Chen et al. set the threshold travel time according to a national recommendation when measuring accessibility to healthcare services in Nanjing. Setting threshold travel times without regard to local specificity would differ from the actual scenario since travel times to certain facilities vary by region.

Luo et al. (2012) proposed a new method to dynamically determine physician and population catchment sizes by incrementally increasing the catchment until a base population and a physician-to-population ratio are met; Tao et al. (2014) set different catchment sizes according to the service capacity of the facility. The larger the service capacity of the facility, the larger the catchment sizes. The base population, the physician-to-population ratio, and the correspondence between catchment sizes and service capacity are set by experts. However, these studies focus on hospital accessibility. There is no recommended base population and supply-to-demand ratio for other types of facilities.

Note that threshold travel time is not how much individuals are willing or even able to travel, but rather a threshold for how much (at most) they should travel (Páez et al., 2020). Threshold travel time (t_0) should be set to ensure that most older adults can access at least one facility within the catchment area centered on the demand points (Chen et al., 2021). Therefore, this study proposes a straightforward approach to set the threshold travel time based on real-world travel time.

1.3 RESEARCH GOAL AND OBJECTIVES

Although older adults face a range of challenges and barriers to completing trips, there are few methods available to help transportation planners and decision-makers identify unique accessibility challenges experienced by older adults. Older adults' accessibility issues might be significantly different from other generation populations. However, common practices in transportation planning rely on national or regional travel surveys and census data representative of the general population, lacking consideration of older people's unique vulnerabilities.

To address these research gaps, this project examines older adults' travel behavior and accessibility by adopting a mixed-method approach. Specifically, our objectives are:

- To examine older adults' travel behaviors and satisfaction using travel surveys tailored to older adults;
- To understand the challenges and opportunities of transportation for older adults using qualitative methods; and
- To develop an integrated accessibility measure that reflects older adults' mobility patterns.

This research contributes significantly to our understanding of travel behavior from the perspective of older adults and informs transportation policies to meet the growing need of an aging population in a post-pandemic world.

2.0 METHODOLOGY

2.1 TRANSPORTATION SURVEY OF OLDER ADULTS

The research team conducted a statewide survey of Utah residents over the age of 50 to assess older adults' travel behavior and satisfaction, as well as their socio-demographics. To increase the response rate and capture a diverse population, the survey was available in two formats: an online version using Qualtrics and a paper version with a prepaid, self-addressed envelope. The researchers recruited the survey participants using different channels, including the Research Participant Registry (RPR) of the Center on Aging at the University of Utah, Wasatch Front Regional Council (WFRC), Utah Transit Authority , Utah Commission on Aging, and Healthy Aging and

Resilient Places Lab. Along with the University of Utah Institutional Review Board (IRB) for the project, the research team went through the Utah State Department of Human Services IRB to collaborate with the Aging and Adult Services of Salt Lake County to distribute surveys through senior centers and other programs such as Meals on Wheels and Rides for Wellness. The study had a total of 830 responses, with 176 coming from the online survey and 654 from the paper survey. No differences on key outcome and demographic measures were found between the online and the paper version. We dropped some responses due to lack of survey eligibility, missing information, or incomprehension, and this resulted in 724 responses for the analysis. Figure 1 illustrates the study area and the distribution of the participants across the region based on the ZIP code location of the participants' residences.

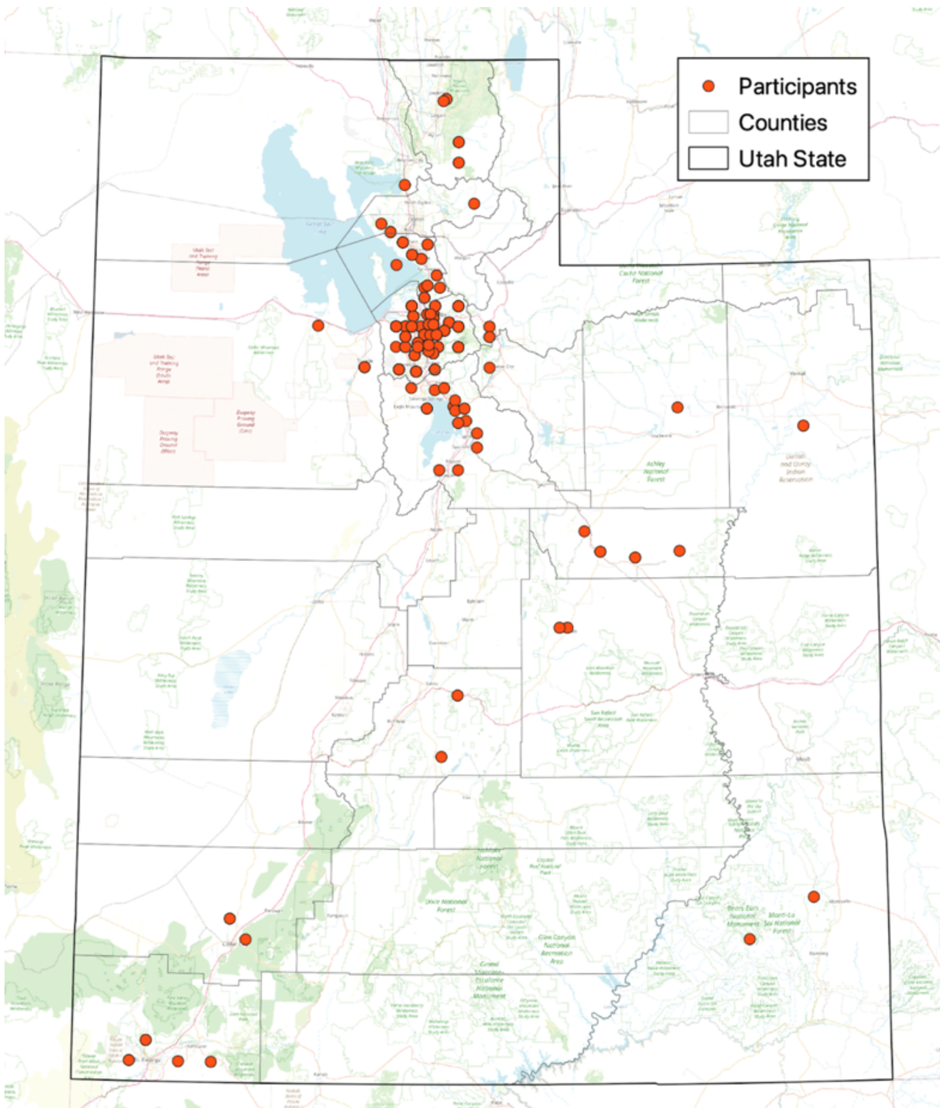


Figure 2.1: Study area and survey participant location

The survey asked the participants to rank their four most preferred activities and included questions about their travel to do each activity. Older adults' travel behaviors were measured with travel frequency, travel time, and travel distance. Travel frequency was measured in eight ordinal categories, from several times a day to never. Travel time and distance were directly asked in minutes and miles, respectively. In order to measure the overall travel behaviors and satisfaction, the research team calculated the mean value for these travel behavior variables. Travel satisfaction was measured using the five-level Likert scale: dissatisfied, somewhat dissatisfied, neutral, somewhat satisfied, and satisfied. Also, the mean travel satisfaction for all activities was used in the analysis. In this study, we also collected the socio-demographic, health, and travel characteristics of the participants: age category, sex, race, ethnicity, education, household income, general health, the primary mode of transportation, their use of public transit and mobility aids such as canes, walkers, wheelchairs, or scooters.

2.2 TRANSPORTATION FOCUS GROUP

The research team conducted focus group interviews to better understand the lived experiences of older adults regarding their transportation behaviors. Focus group participants were recruited based on survey respondents' interests in participating in follow-up studies. Four separate focus groups were conducted: two in June 2022 and the other two in November 2022. Each focus group had four to five participants with a facilitator. Each focus group took about an hour, and the participants were compensated with a $30 gift card. During the focus groups, the participants had the opportunity to share their experiences and thoughts about transportation services/resources and their accessibility. A total of 18 older adults participated in the focus groups, and they all resided in Salt Lake County, Weber County, and Box Elder County.

The focus group interviews were audio-recorded with the consent of the participants and transcribed with pseudonyms to deidentify participants. The research team used MAXQDA 2022, a qualitative data analysis software, to analyze transcribed data systematically (VERBI Software, 2021). The researchers first read the entire transcript and used an inductive approach to create a set of initial codes such as transportation mode, current travel behavior, future travel behavior, and attitude. Then, the participants were grouped in terms of their multimodal behaviors, and several themes emerged as a result of the researchers' collaborative work to look for patterns and themes in the transcripts. The themes were reviewed and constantly modified by the team.

2.3 ACCESSIBILITY OF OLDER ADULTS

2.3.1 The 2SFCA Method

2.3.1.1 Overview

The 2SFCA method has been widely applied as a simple and intuitive approach for measuring the spatial accessibility of the population within a given area. As shown in Figure 2.2, 2SFCA involves two major steps.

Step 1: For each supply point j, the catchment area within a threshold travel time (t_0) is generated and used to search all demand points k and calculate the ratio of supply to demand R_j via the following formula:

$$R_j = \frac{S_j}{\sum_{k\in\{t_{kj}\le t_0\}} D_k f(t_{kj})}, f(t_{kj}) = \begin{cases} f(t_{kj}), if \ \ t_{kj} \le t_0 \\ 0, \qquad if \ \ t_{kj} > t_0 \end{cases} \qquad (2-1)$$

where S_j is the supply volume (e.g., the area of facilities) at supply point j; t_{kj} is the travel time between k and j; D_k is the demand volume (e.g., older adult population) at demand point k that falls within the catchment area of j ($t_{kj} \le t_0$); $f(t_{kj})$ is the generalized decay function.

Step 2: For each demand point i, the catchment area within a threshold travel time (t_0) is generated and used to search all supply points j and sum up the R_j ratios via the following formula:

$$A_i = \sum_{j\in\{t_{ij}\le t_0\}} R_j f(t_{ij}) \qquad (2-2)$$

where A_i denotes the accessibility at demand point i, R_j is the ratio of supply to demand at supply point j that falls within the catchment area of i ($t_{kj} \le t_0$), and t_{kj} is the travel time between i and j.

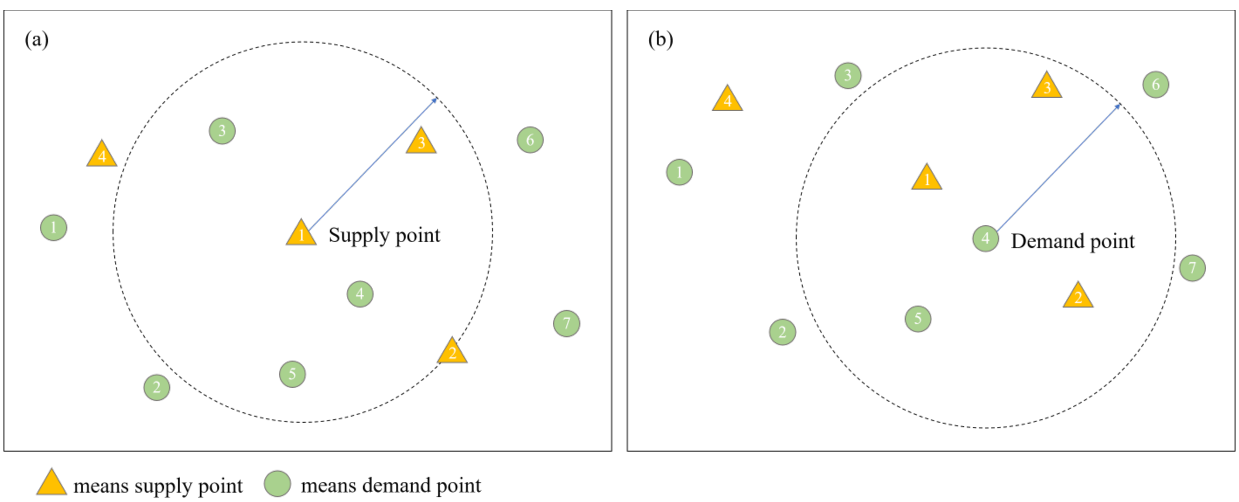


Figure 2.2: The 2SFCA method: (a) step 1 and (b) step 2

2.3.1.2 Decay Functions

Based on past examples of the 2SFCA applications, we proposed an analytic framework that includes four distance decay functions: the inverse-power gravity-type (POW); exponential gravity-type (EXP); Gaussian gravity-type (GAUSS); and kernel density (KD) models, as shown in Table 2.1. The distance decay function yields a value of 0 (KD) or 0.01 (POW, EXP, and GAUSS) at the boundary, where the distance impedance coefficient β in each model is determined by t_0, correspondingly. The choice of 0.01 is based on Wan et al. (2012): 0.01 is considered a critical value when the distance decay function converges to 0. t_0 of shopping, meals, recreational, healthcare, and religious facilities are 8, 8, 7, 13, 10 minutes, respectively, calculated in Section 3.5.

Table 2.1: Analytic Framework Consisting of Four Decay Functions in the 2SFCA Method

	t_0 (min)	β	applications
POW: $f(t) = t^{-\beta}$	8	2.2	Yao et al. (2013)
	8	2.2	
	7	2.4	
	13	1.8	
	10	2	
EXP $f(t) = e^{-\beta t}$	8	0.6	Jamtsho et al. (2015)
	8	0.6	
	7	0.7	
	13	0.4	
	10	0.4	
GAUSS $f(t) = e^{-\frac{t^2}{\beta}}$	8	13.9	Dai (2010)
	8	13.9	
	7	10.6	
	13	36.7	
	10	21.7	
KD $f(t) = 0.75[1 - (\frac{t}{t_0})^2]$	8		Dai and Wang (2011)
	8		
	7		
	13		
	10		

We then employed the Root Mean Square Error (RMSE) to evaluate the goodness of fit between $\overline{A_i}$ and the A_i obtained by using POW, EXP, GAUSS, and KD as decay function (Chen et al., 2019). $\overline{A_i}$ is the average accessibility index for each demand point by the above five models. The RMSE was derived between the average accessibility ($\overline{A_i}$) and each 2SFCA model applied.

Table 2.2: The Evaluation of the 2SFCA Modeling Results

	RMSE with shopping $\overline{A_i}$	RMSE with meals $\overline{A_i}$	RMSE with recreational $\overline{A_i}$	RMSE with healthcare $\overline{A_i}$	RMSE with religious $\overline{A_i}$
POW	1.22	0.40	97.98	4.61	15.87
EXP	0.54	0.12	16.18	4.48	5.17
GAUSS	1.76	0.61	88.76	5.27	5.33
KD	1.70	0.55	117.99	9.04	5.49

As shown in Table 2.2, the EXP function performs the best among others with the smallest RMSE for all types of destinations.

2.3.1.3 Generalized Time

Generalized time is a measure to evaluate the overall cost of a trip or a mode of transportation, taking into account not only non-monetary costs (travel time) but also monetary costs (Goodwin, 1974; Odoki et al., 2001). Generalized time provides a more comprehensive measure of the true cost of travel than just considering non-monetary costs or monetary costs alone. According to the 2012 Utah Household Travel Survey, car trips make up 90.9% of all journeys of older adults in Salt Lake County. Therefore, this study focuses on vehicle trips.

The generalized time expenditure on travel, g_t, can be defined as

$$g_t = t + \frac{m}{\lambda} \tag{2-3}$$

where t is the amount of time spent, m is the amount of money spent, and λ is the value of time. λ describes how much extra time a person will travel to achieve or compensate for a unit change in money cost. To calibrate λ, we first analyze the relationship between the distance traveled, the time spent traveling, money spent on travel, and income (Goodwin, 1974; Odoki et al., 2001). Based on the 2017 National Household Travel Survey (NHTS) data, we can get Table 2.3. According to the NHTS Users' Guide, vehicle trips are obtained by filtering trip records where a household member was the driver (DRVR_FLG = 01) of a single, privately operated vehicle (TRPTRANS = [03, 04, 05, 06, 08, 09, 18]). The NHTS data does not have an explicit variable to show the monetary cost of trips. Therefore, we calculated the monetary cost of a vehicle trip by fusing the trip record and vehicle record. Specifically, the monetary costs can be calculated as

$$m = P\frac{1}{MPG}d \tag{2-4}$$

where *P* is the price of gasoline on the respondent's travel day, *MPG* is the fuel economy of vehicles (miles per gallon), and *d* is travel distance.

Table 2.3: NHTS Data Analysis

Household income class	Household income ($)	Average travel time per trip (min)	Average travel distance per trip (miles)	Average monetary cost per trip ($)
1	Less than $10,000	19.43	8.75	1.02
2	$10,000 to $14,999	18.21	7.63	0.89
3	$15,000 to $24,999	17.90	7.91	0.91
4	$25,000 to $34,999	18.43	8.19	0.94
5	$35,000 to $49,999	19.12	8.62	0.99
6	$50,000 to $74,999	19.56	9.25	1.06
7	$75,000 to $99,999	20.21	9.85	1.12
8	$100,000 to $124,999	20.68	10.13	1.16
9	$125,000 to $149,999	20.83	10.14	1.15
10	$150,000 to $199,999	20.94	10.40	1.18
11	$200,000 or more	21.27	10.34	1.20

In terms of the overall trends, the distance traveled, the time spent traveling, and the money spent on travel all increased with income. Linear, power, logarithmic or logistic curves can all be fitted well to these data. In terms of the proportion of variation explained, there is no strong case for choosing one form over others. Let *t* be the average travel time per trip (in minutes), *d* be the distance (in miles), *m* be the money spent (in cents), and *I* will be the income. For the sake of computational simplicity (Goodwin, 1974), the data may be approximately fitted as:

$$t = 17.83I^{0.06} \quad (2-5)$$
$$d = 7.45I^{0.13} \quad (2-6)$$
$$m = 86.85I^{0.12} \quad (2-6)$$

In this form, the rate of change of the different measures of travel may be more conveniently compared. While the time spent traveling increases roughly in proportion to disposable income, distance traveled increases more rapidly and money spent more rapidly still, as higher-income groups travel more by faster and more expensive modes.

Within the range of the data, it is possible to derive so-called "values of time" from these relationships. Let *p* equal the money cost per mile paid for travel and *h* the time spent per mile, then we get:

$$p = \frac{m}{d} = 11.66I^{-0.01} \quad (2-7)$$
$$h = \frac{t}{d} = 2.39I^{-0.07} \quad (2-8)$$

If only time and cost factors enter into the decisions, which lead to particular time and expenditure totals for a given distance of travel, the value of time λ for an income group *j* will be measured by the extra money paid to make a unit time saving, compared with another income group $(j-1)$:

$$\lambda = \frac{p_j - p_{j-1}}{h_j - h_{j-1}} \quad (2-9)$$

which in the limit becomes:

$$\lambda = \frac{dp}{dh} \quad (2-10)$$

Let,

$$p = aI^A \quad (2-11)$$

$$h = bI^B \quad (2-12)$$

Then,

$$\lambda = \frac{dp}{dI}\frac{dI}{dh} = \frac{a}{b}\frac{A}{B}I^{A-B} = 0.69I^{0.06} \quad (2-13)$$

Introducing generalized time as the spatial impedance, we can obtain an adjusted 2SFCA method with a decay function incorporating time and cost (referred to as TC 2SFCA):

$$A_i = \sum\nolimits_{j\in\{t_{ij}\le t_0\}} R_j = \sum\nolimits_{j\in\{t_{ij}\le t_0\}} \frac{S_j F(g_{t,ij})}{\sum_{k\in\{t_{kj}\le t_0\}} D_k F(g_{t,kj})} \quad (2-14)$$

$$F(g_{t,kj}) = \begin{cases} e^{-\beta\left(t_{kj}+\frac{\mu d_{kj}}{0.69 I_k^{0.06}}\right)}, & if \;\; t_{kj} \le t_0 \\ 0, & if \;\; t_{kj} > t_0 \end{cases} \qquad (2-15)$$

where $g_{t,kj}$ is the generalized time between k and j; $g_{t,ij}$ is the generalized time between i and j; d_{kj} is the travel distance between demand point k and supply point j; μ refers to the travel cost per unit distance (dollar per passenger-mile); I_k is the average income of older adults at demand point k.

2.3.1.4 Threshold Travel Time Calculation

The real-world travel time and distance were obtained from recommended route planning for traveling and corresponding travel time and distance features in Google Maps. In this study, we used the Distance Matrix API in Google Maps to get the travel distance and time for a matrix of origins and destinations from the JSON file it returns, which were saved to our local database. The data collection framework is described in Figure 2.3. Note that the range of departure times is constrained to between 9 a.m. and 5 p.m. since older individuals are more likely to travel during off-peak times to avoid crowds (Guo et al., 2019). During that period, there were merely slight variations in travel times (Chen et al., 2021).

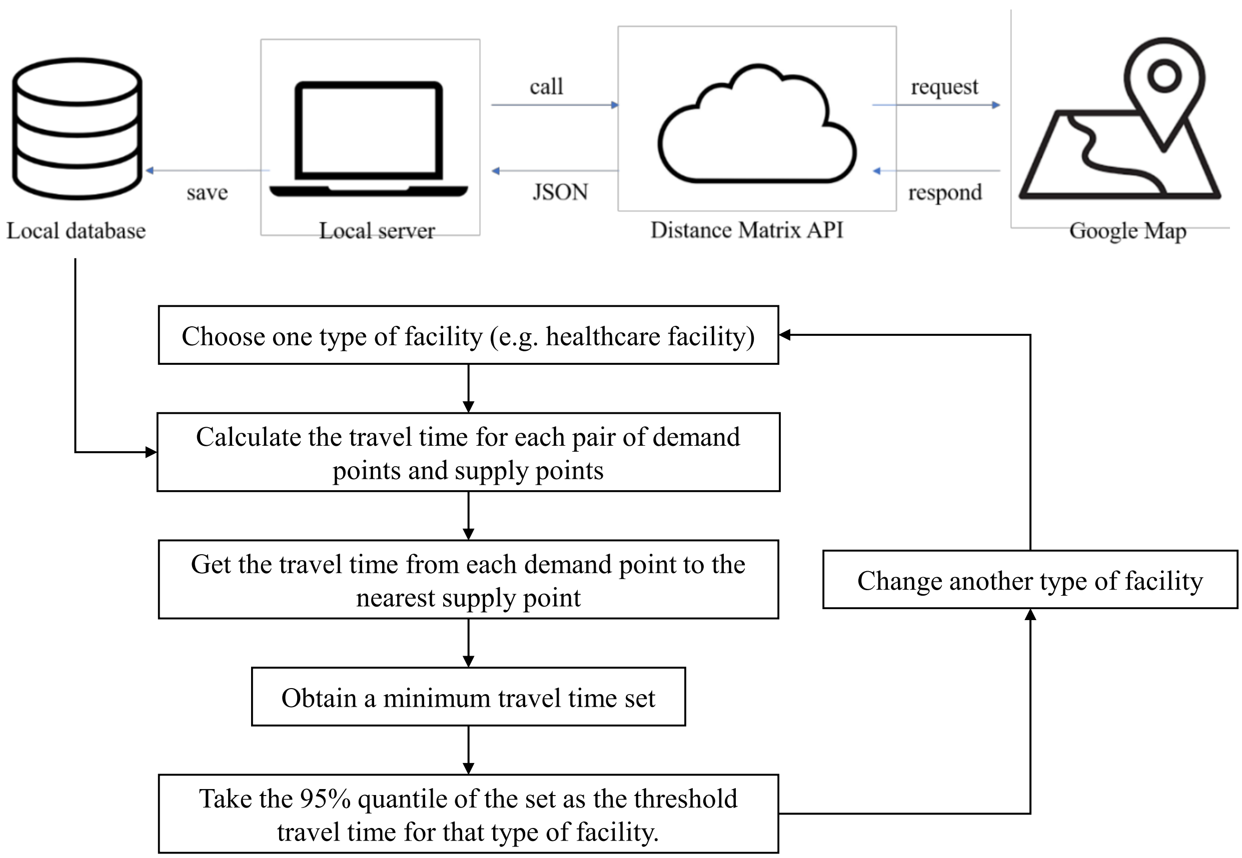


Figure 2.3: Framework of crawling and calculating threshold travel times

This study sets the catchment area based on real-world travel time. Travel time and travel distance between supply points and demand points were estimated by the Google Map Distance Matrix API. The threshold travel time (t_0) was set to ensure that most older adults can access at least one facility within the catchment area centered on the demand points (Chen et al., 2021) via the following process:

(1) For one type of facility, we estimated the travel time from each demand point to each supply point to get the travel time matrix;
(2) We calculated the minimum travel time to reach supply points for each demand point to get the minimum travel time set;
(3) Took the 95% quantile of the set as the threshold travel time for that type of facility; and
(4) Repeated the steps above for all types of facilities.

We made an assumption that most travels by older adults would fall within a 60-minute catchment area. However, some older adults may live far from destinations (e.g., 60 minutes), which presents an extreme case. The catchment area could lose its significance if we take the maximum of the set as the threshold travel time. In statistics, 95% of the data can be regarded as the majority. In other words, most older adults can access at least one facility within the threshold travel time estimated above.

2.3.2 An Integrated Accessibility Measure

According to the method in Section 2.3.1, the accessibility to different destinations can be calculated. To calculate accessibility to all types of service facilities, accessibility should be evaluated from a comprehensive perspective. First, accessibility scores were normalized through Eq. (2-16), which transforms the values of original accessibility into values between 0 and 1 and compares the relative accessibility among service facilities.

$$A_i^{\varphi\prime} = \frac{A_i^{\varphi} - min(A_i^{\varphi})}{max(A_i^{\varphi}) - min(A_i^{\varphi})} \qquad (2-16)$$

where A_i^{φ} is the accessibility score of facility φ in demand point i; $A_i^{\varphi\prime}$ is the relative accessibility score after being normalized; $max(A_i^{\varphi})$ and $min\ (A_i^{\varphi})$ are the maximum and the minimum of the accessibility.

Then, the comprehensive accessibility score A_i to all types of service facilities from each census tract is calculated through Eq. (2-17).

$$A_i = \frac{1}{\sum_{\varphi} f_{\varphi}} \sum_{\varphi} f_{\varphi} A_i^{\varphi\prime} \qquad (2-17)$$

where f_{φ} is the frequency that people access facility φ; $\frac{f_{\varphi}}{\sum f_{\varphi}}$ is the weight of facility φ.

3.0 RESULTS AND FINDINGS

3.1 TRAVEL BEHAVIOR AND TRAVEL SATISFACTION

3.1.1 Descriptive Summary of the Survey Participants

The survey participants were distributed across various age groups, ranging from those aged 50 to 59 to those aged 90 and older. More than half of the participants were between the ages of 60 and 79, and the largest proportion of participants fell within the age bracket of 70 to 79 years. There was a statistically significant difference in race distribution between urban and rural areas, with a higher percentage of whites in rural areas. Most participants were female and white. In terms of household income, urban areas had a greater proportion of individuals with lower incomes. Urban areas had a higher proportion of individuals using mobility aids such as canes, wheelchairs, and scooters. General health conditions were marginally higher in rural areas than in urban ones. Although there were no significant differences between urban and rural areas in terms of travel frequency, travel time, or travel satisfaction, participants in rural areas had longer travel distances (Table 3.1).

Table 3.1: Descriptive Summary of the Survey Participants

Variables	**Utah**[1]	**Survey**		
	Overall	**Overall** (N=724)	**Urban** (N=503)	**Rural** (N=221)
Age group				
50-59 years old	314,550 (9.7%)	57 (7.9%)	32 (6.4%)	25 (11.3%)
60-69 years old	280,357 (8.5%)	187 (25.8%)	126 (25.0%)	61 (27.6%)
70-79 years old	165,204 (5%)	272 (37.6%)	190 (37.8%)	82 (37.1%)
80-89 years old	43,796 (1.3%)	144 (19.9%)	105 (20.9%)	39 (17.6%)
90+	37,359 (1.1%)	50 (6.9%)	40 (8.0%)	10 (4.5%)
Missing		14 (1.9%)	10 (2.0%)	4 (1.8%)
Sex				
Male	328,360 (48%)	256 (35.4%)	178 (35.4%)	78 (35.3%)
Female	352,568 (52%)	451 (62.3%)	311 (61.8%)	140 (63.3%)
Missing		17 (2.3%)	14 (2.8%)	3 (1.4%)
Race[2]				
White	2,918,244 (88.9%)	578 (79.8%)	389 (77.3%)	189 (85.5%)
Hispanic	480,843 (14.6%)	35 (4.8%)	29 (82.9%)	6 (17.1%)
Black or African American	66,891 (2%)	8 (1.1%)	8 (1.6%)	0 (0%)
American Indian or Alaska Native	69,203 (2.1%)	5 (0.7%)	2 (0.4%)	3 (1.4%)
Asian	123,221 (3.8%)	16 (2.2%)	14 (2.8%)	2 (0.9%)
Native Hawaiian or Pacific Islander	53,798 (1.6%)	7 (1.0%)	7 (1.4%)	0 (0%)
Other	298,412 (9.1%)	26 (3.6%)	21 (4.2%)	5 (2.3%)
Missing		96 (13.3%)	71 (14.1%)	25 (11.3%)
Household Income[2]				
< $30,000	160,535 (16%)	248 (34.3%)	204 (40.6%)	44 (19.9%)
$30,000 - $59,999	310,034 (31%)	129 (17.8%)	92 (18.3%)	37 (16.7%)
$60,000 +	495,652 (49%)	230 (31.8%)	120 (23.9%)	110 (49.8%)
Missing		117 (16.2%)	87 (17.3%)	30 (13.6%)
General Health				
Mean (SD)		3.01 (1.05)	2.88 (1.04)	3.29 (1.00)
Median [Min, Max]		3.00 [1.00, 5.00]	3.00 [1.00, 5.00]	3.00 [1.00, 5.00]
Missing		57 (7.9%)	41 (8.2%)	16 (7.2%)

Mobility Aid				
Yes		273 (37.7%)	213 (42.3%)	60 (27.1%)
No		434 (59.9%)	277 (55.1%)	157 (71.0%)
Missing		17 (2.3%)	13 (2.6%)	4 (1.8%)
Travel Frequency				
Mean (SD)		15.2 (4.05)	15.1 (4.06)	15.4 (4.04)
Median [Min, Max]		16.0 [1.00, 28.0]	16.0 [5.00, 28.0]	16.0 [1.00, 26.0]
Missing		205 (28.3%)	154 (30.6%)	51 (23.1%)
Travel Time				
Mean (SD)		64.6 (27.9)	63.0 (27.5)	67.7 (28.5)
Median [Min, Max]		60.0 [13.0, 150]	58.0 [13.0, 150]	65.0 [17.5, 150]
Missing		280 (38.7%)	214 (42.5%)	66 (29.9%)
Travel Distance				
Mean (SD)		29.8 (18.5)	28.4 (18.5)	32.5 (18.3)
Median [Min, Max]		26.1 [1.75, 88.0]	25.0 [1.75, 88.0]	29.0 [2.00, 87.0]
Missing		303 (41.9%)	227 (45.1%)	76 (34.4%)
Travel Satisfaction				
Mean (SD)		17.8 (3.46)	17.8 (3.44)	17.9 (3.52)
Median [Min, Max]		20.0 [4.00, 20.0]	20.0 [4.00, 20.0]	20.0 [4.00, 20.0]
Missing		170 (23.5%)	130 (25.8%)	40 (18.1%)

Note: [1] Derived from ACS 2020 (5-yr estimates); [2] Estimates are for all population in Utah, not just for older adults

While the survey's sex and race distribution reflects Utah's demographics, the participant pool skews older and has a lower income level compared to the general population. This is because we intentionally oversampled older adults, and income tends to decrease with age. We also observed a lower number of Hispanic participants compared to the overall population.

Regarding the activities, the research team determined the overall activity frequencies based on the top four desired activities of the participants. Most people spent the majority of their time engaging in social activities such as getting together with friends and relatives. Going shopping was the second most common thing that people did. The participants were questioned individually about their participation in cultural and physical activities; nevertheless, if we add all recreational activities, this would be the most frequent activity of all. In addition, going out to eat at a restaurant or having a drink at a café or a bar is something that happens on occasion (Table 3.2).

Table 3.2: Activity Frequency

Category	Activities	Percentage
Shopping	Go grocery/clothes shopping	16.23%
Healthcare	Go to hospitals/pharmacies/clinics	6.29%
Education	Access educational and training opportunities	3.74%
Employment	Access employment opportunities (job, volunteering)	4.74%
Meals	Eat at a restaurant	11.57%
	Have a drink at a café or a bar	4.00%
Social activity	Meet up with family/friends	17.99%
Recreation	Go to movie, a theater, a concert, a museum, or an art gallery	5.57%
	Do drawing, singing, knitting, pottery, or other hobbies	7.15%
	Go to a park or a gym, play golf, do swimming, dance, yoga, or other exercises	9.20%
Religion	Go to church/temple	8.72%
Political activity	Do political activities	0.77%
Missing	Missing	4.04%

3.1.2 Travel Behavior

We examined the participants' travel behaviors by looking at travel frequency, travel time, and travel distance. We developed models that examined each of these travel behaviors as a function of socioeconomics, health, use of assistive devices, and urban/rural residence. The regression model results are shown in Table 3.3. High-income persons exhibited a positive correlation with travel frequency, in contrast to other demographic factors such as age groups, sex, and race, which did not have a significant relationship with any travel behaviors. A negative correlation was found between urban residence and both travel time and travel distance. There was a significant positive relationship between general health status and travel frequency, but there was no significant relationship with travel time and distance. The number of times that participants who used assistive equipment traveled had a negative correlation, but the amount of time spent traveling had a positive correlation.

Table 3.3: Factors Affecting Travel Behaviors of Older Adults

Variable	**Travel Frequency**	**Travel Time**	**Travel Distance**
	B (SE)	B (SE)	B (SE)
Age: 60-69 years old	0.034 (-0.627)	-6.4 (-5.213)	-2.19 (-3.583)
Age: 70-79 years old	-0.141 (-0.61)	-6.857 (-5.084)	-5.588 (-3.482)
Age: 80-89 years old	0.251 (-0.705)	-2.632 (-5.829)	**-6.783*** (-4.022)
Age: 90+	1.088 (-1.063)	-7.69 (-8.886)	-6.919 (-6.105)
Sex: Female	-0.055 (-0.367)	-0.978 (-2.976)	2.351 (-2.005)
Race: Nonwhite	0.89 (-0.666)	-2.65 (-5.256)	5.503 (-3.571)
Income: High Income	**1.587***** (-0.413)	-4.042 (-3.389)	1.631 (-2.345)
Urban/Rural: Urban	0.566 (-0.385)	**-8.104***** (-3.058)	**-5.188**** (-2.118)
General Health	**0.670***** (-0.198)	-1.546 (-1.576)	-0.755 (-1.076)
Assistive Device: Yes	**-1.409***** (-0.448)	**9.884***** (-3.711)	3.898 (-2.504)
Constant	**12.047***** (-0.943)	**80.705***** (-7.831)	**35.944***** (-5.374)
N	434	382	362
R^2	0.148	0.061	0.047
Adjusted R^2	0.128	0.036	0.019
Residual Std. Error	3.647 (df = 423)	27.529 (df = 371)	18.310 (df = 351)
F Statistic	7.354*** (df = 10; 423)	2.404*** (df = 10; 371)	1.714* (df = 10; 351)

*Note: *p<0.1; **p<0.05; ***p<0.01*

3.1.3 Travel Satisfaction and Travel Behavior

After examining the relationship between travel behaviors and individual factors, we examined the association between travel satisfaction and travel behaviors. Table 3.4

shows the results of the regression models. Each model examines the relationship between travel satisfaction and travel frequency, travel time, travel distance, and the most preferred activity, respectively. The results showed that people who are 90 years and above were negatively correlated with travel satisfaction across all models. It was shown that participants who lived in urban areas and had higher incomes had a more positive association with travel satisfaction. In terms of one's health, overall health status was shown to have a positive relationship with travel satisfaction; however, the use of assistive devices was found to have a negative relationship with travel satisfaction in comparison to individuals who do not rely on any assistive device.

Although the result showed that travel time and travel distance were not significantly related to travel satisfaction, the relationship between travel frequency and travel satisfaction was very interesting. In order to examine nonlinear relationships for the given predictor variables, we used a generalized additive model to examine the relationship. As shown in Figure 3.1, travel satisfaction increases with travel frequency. However, when travel frequency increases beyond a certain threshold (approximately 17 trips), travel satisfaction seems to decrease. Lastly, the result shows that social activities such as meeting family and friends or going to a café or bar had a significantly positive relationship with travel satisfaction among older adults. We further examined the relationship by stratifying the data by urban/rural residence, which is shown in Figure 3.2. The stratified model shows that the positive relationship between social destinations and travel satisfaction is only found in rural areas, whereas no significant relationships were found in urban areas.

Table 3.4: Relationship between Travel Satisfaction and Travel Behavior of Older Adults

Variable	Travel Satisfaction			
	Model 1	Model 2	Model 3	Model 4
	B (SE)	B (SE)	B (SE)	B (SE)
Age: 60-69 years old	**-0.915* (-0.544)**	-0.697 (-0.567)	-0.794 (-0.593)	**-1.276** (-0.564)**
Age: 70-79 years old	-0.171 (-0.53)	-0.035 (-0.553)	0.208 (-0.578)	-0.463 (-0.553)
Age: 80-89 years old	-0.058 (-0.61)	-0.031 (-0.634)	0.347 (-0.669)	-0.548 (-0.636)
Age: 90+	**-2.875*** (-0.931)**	**-3.081*** (-0.965)**	**-2.709*** (-1.012)**	**-3.255*** (-0.916)**
Sex: Female	0.02 (-0.316)	0.038 (-0.323)	0.327 (-0.333)	-0.001 (-0.315)
Race: Nonwhite	0.465 (-0.584)	0.245 (-0.578)	0.592 (-0.593)	0.782 (-0.575)
Income: High Income	**1.187*** (-0.365)**	**0.886** (-0.371)**	**1.371*** (-0.388)**	**1.030*** (-0.356)**
Urban/Rural: Urban	**0.559* (-0.332)**	**0.569* (-0.336)**	0.545 (-0.353)	0.496 (-0.333)
General Health	**0.759*** (-0.174)**	**0.533*** (-0.173)**	**0.528*** (-0.179)**	**0.859*** (-0.17)**
Assistive Device: Yes	**-0.826** (-0.393)**	**-1.095*** (-0.407)**	**-1.263*** (-0.416)**	**-0.814** (-0.377)**
s(Travel Frequency): curvilinear smooth term	**F(3.58)****			
Travel Time		-0.001 (-0.006)		
Travel Distance			0.002 (-0.009)	
First Preferred Activity: Hospital/Pharmacy				-0.441 (-0.618)

First Preferred Activity: Education				0.608 (-0.987)
First Preferred Activity: Employment				0.087 (-0.753)
First Preferred Activity: Restaurant				0.369 (-0.573)
First Preferred Activity: Cafe/Bar				**2.491** (-1.056)**
First Preferred Activity: Family/Friend				**1.255*** (-0.425)**
First Preferred Activity: Theater/Gallery				1.409 (-1.05)
First Preferred Activity: Hobby				0.226 (-0.872)
First Preferred Activity: Exercise				0.252 (-0.595)
First Preferred Activity: Church/Temple				1.009 (-0.625)
First Preferred Activity: Political Activity				2.556 (-3.169)
Constant	15.010*** (-0.822)	16.136*** (-0.97)	15.351*** (-0.946)	14.618*** (-0.858)
Observations	421	378	361	457
R2		0.165	0.205	0.238
Adjusted R2	0.205	0.14	0.18	0.201
Log Likelihood	-1,080.84			
UBRE	9.905			
Residual Std. Error		2.986 (df = 366	3.028 (df = 349	3.133 (df = 435)
F Statistic	3.58** (edf = 2.63)	6.594*** (df = 11; 366)	8.204*** (df = 11; 349)	6.453*** (df = 21; 435)

*Note: *p<0.1; **p<0.05; ***p<0.01*

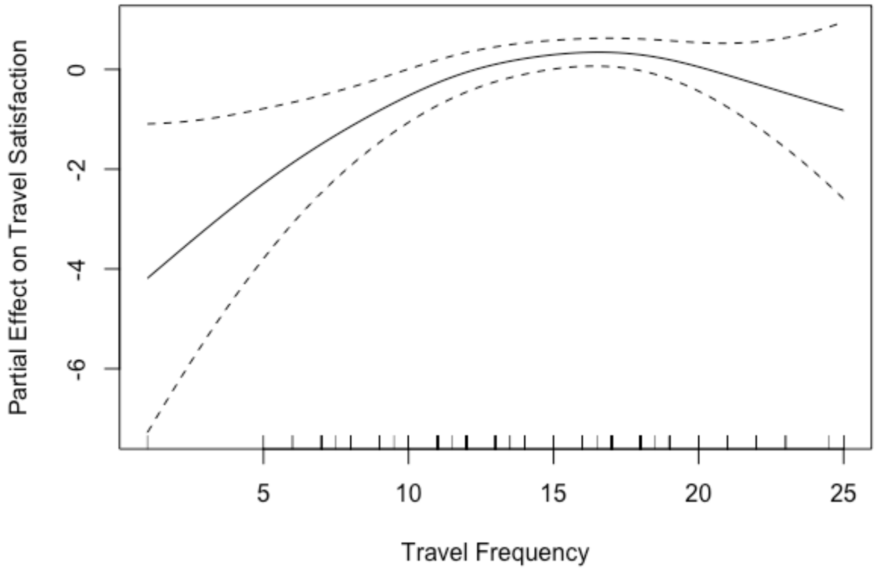


Figure 3.1: Effect of travel frequency on travel satisfaction

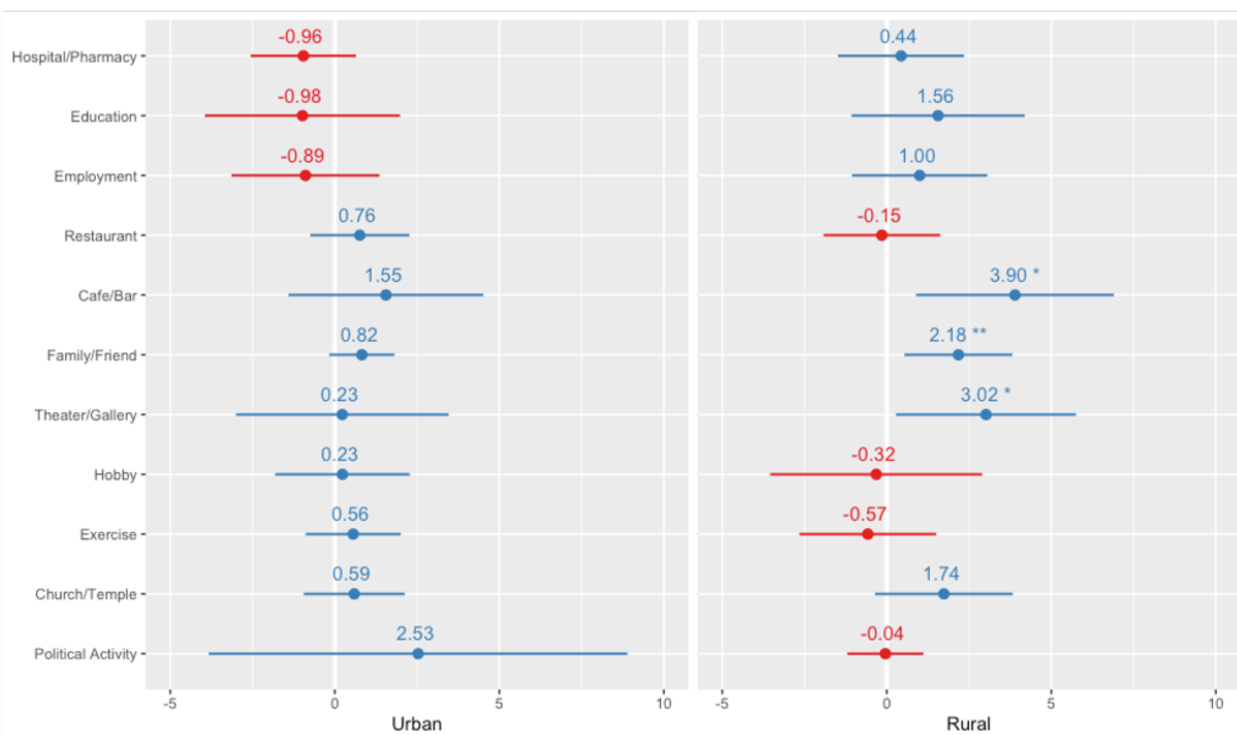


Figure 3.2: Activity destinations and travel satisfaction by residential location

3.1.4 Discussion

3.1.4.1 Wide Spectrum of an Aging Population

This study confirms that older adults are not a homogeneous group. Travel behaviors of older adults vary by their age, income, health status, mobility-related disabilities, and surrounding built environments. Although our study didn't show the significance of all variables in travel behaviors, travel distance among the group aged between 80 and 89 was significantly lower, suggesting that this might be the age group that experiences a noticeable decline in health and, in turn, adjusts their travel behaviors accordingly (e.g., shorter trips). In terms of travel satisfaction, we found that those who were 90 and older had significantly lower satisfaction compared to other groups. Generally, the oldest group is 85 years and older, showing the negative impact of aging on travel. Considering the study is community-based, targeting non-hospitalized older adults, we had a slightly older group who showed limited mobility difficulties in travel, resulting in significant dissatisfaction with their travel. It is also supported by the association between travel satisfaction and health status, and the use of assistive devices.

3.1.4.2 Nonlinear Relationship between Trip Frequency and Travel Satisfaction

We found a nonlinear relationship between travel frequency and travel satisfaction. In fact, older adults' travel satisfaction started to decline beyond a certain threshold – in our case, the threshold point appears to be around 17 trips. Prior studies of well-being have shown that mobility is linearly related to life satisfaction, assuming that more travel would lead to higher life satisfaction (Delbosc & Currie, 2018). However, there have been different arguments on this relationship, speculating that more journeys would not provide the same benefits to well-being. Diminishing return on life satisfaction has been found in other studies. For example, higher income does not always result in more happiness (Kahneman & Deaton, 2010). Similarly, the present study found some evidence of diminishing marginal returns associated with increasing trip frequency. Further research would be needed to confirm whether this nonlinear relationship with trip frequency exists in other older adult populations.

3.1.4.3 Health and Travel Behavior

As shown in the results of our study, older adults' health conditions influenced their travel behavior and satisfaction. However, it can also be argued that travel itself can affect one's health. Current literature extensively argues that maintaining walking can be one of the best interventions for older adults to keep active and healthy. However, there has been comparably less attention on the benefit of all travel regardless of the mode of transportation. Our results indicated that social activities such as meeting friends and family or going to third places to connect with people, such as cafés or bars, significantly increased travel satisfaction among older adults. Similar results were found in other studies that examined the beneficial aspects of maintaining individual mobility in later life. Having good mobility was positively related to social connection (Yen et al., 2012) and contributed to mental health (Freedman et al., 2017). It is important to consider encouraging all travel behaviors, as well as walking and physical activity, to support healthy aging and quality of life.

3.1.4.4 Urban/Rural Differences in Travel Activities and Satisfaction

Our results showed that meeting friends and family or going to a café or bar was positively related to travel satisfaction in older adults (Table 3.4). In order to examine further, we looked at the relationship between urban and rural locations. As Figure 3.2 illustrates, only the rural participants' travel satisfaction was significantly related to social and cultural activities, such as going to theaters and galleries. This suggests that social and cultural activities were more important for older adults in rural areas in terms of their well-being and quality of life. A study conducted in Korea found that mobility and social participation are important for older adults' life satisfaction, and found no differences between urban and rural areas (Lee & Choi, 2020). In the U.S. context, however, social and cultural amenities are disproportionately distributed between urban and rural areas. While social and cultural destinations are abundant in major U.S. cities, rural areas typically lack major destinations for social and cultural activities. Our results indicate that in such environments with limited amenities, designations that provide social and cultural activities would be important for older adults to maintain their health and well-being. This suggests that more efforts should be made to improve accessibility to social and cultural destinations in rural areas than in urban areas.

3.1.4.5 Limitations

We used two different modes of survey data collection: a paper and an online version. However, paper surveys were our primary data collection method after working with aging service providers and their preferred method of data collection. On the paper survey, some older adults wrote more detailed information about their travel behavior, but we could not capture all that information in our results. Older adult participants appear to be different from the general survey participants – they want to say more about their lives. Therefore, when conducting surveys with older adults, an additional question can be added to assess participants' willingness to participate in quick follow-up interviews to both confirm their survey responses and get more detailed information and insights that cannot be captured through quantitative surveys. The research used cross-sectional data, thus, no causality of the relationship can be determined as the survey only captures a snapshot of the travel behaviors of older adults. Also, the sample is not representative of the entire older adult population in Utah. The survey was distributed in summer and fall so that the responses may be reflective of those seasonal travel behaviors.

3.2 QUALITATIVE ASSESSMENT OF TRAVEL BEHAVIOR

3.2.1 Participant Demographics and Modal Grouping

As Table 3.5 shows, most participants were in their 60s and 70s. The participants were equally distributed by sex, but mostly white or non-Hispanic population, which represents Utah residents. Some participants used mobility aids such as canes, walkers, and wheelchairs. Their education levels were relatively high, and a third had a master's degree or doctoral degree. Regarding household income, we had a more low-income population among the participants. The general health status of the participants was rated above good.

Table 3.5: Summary Characteristics of Focus Group Participants (*n* = 18)

Variable	Category / Range	Percentage / Mean
Age	50-59	11.11%
	60-69	38.89%
	70-79	38.89%
	80-89	11.11%
Sex	Male	50%
	Female	50%
Race	White	66.66%
	Hispanic	5.56%
	Black or African American	5.56%
	Asian	5.56%
	Missing	16.66%
Mobility Aid	Yes	23.53%
	No	77.77%
Education	Some college or Associate degree in college	33.33%
	Bachelor's degree in college	27.78%
	Master's or Doctoral degree	38.89%
Household Income	Less than $30,000	22.22%
	$30,000 - $59,999	27.78%
	$60,000 or more	50%
General Health	[1: Poor, 5: Excellent]	3.39
Primary Mode of Transportation	Walk	5.88%
	Transit	11.76%
	Drive	88.24%
	Get a ride	11.76%
	Paratransit	5.88%
Travel Frequency	Several times a day	29.41%
	Once a day	17.65%
	Several times a week	47.06%
	Once a week	5.88%
	Several times a month	5.88%

Based on the survey responses of the focus group participants, we identified four different groups based on the level of multimodal behavior: super single modal, semi single modal, semi multimodal, and super multimodal. For example, if a participant uses public transportation, all transit modes used are scored respectively. Then, the number of different transportation modes selected for one's primary mode and the modes selected for most preferred activities were also counted and added to the total mode count. The super single-modal group relies solely on one mode of transportation: car driving. The semi single-modal group travels via two modes: driving and public transportation. Nonetheless, the participants in this group primarily drove. The semi multimodal group chose one or two transit modes, driving and walking, giving them three different modes of transportation. Lastly, the super multimodal group is more likely to use multiple modes of transportation, including transit, paratransit, walking, biking, driving, and getting a ride from someone else.

3.2.2 Current and Future Travel Behavior

3.2.2.1 Current Travel Behavior

Figure 3.3a illustrates the current travel behavior by the single and multimodal tendency. The desire to stay independent was shared among all groups, and mode attachment and decisive attitude toward the status quo was mostly observed in single-modal groups. Other tendencies observed from the single and multimodal groups include behaviors affected by past experience, activities for fun/family activities, and the use of ride-hailing services. Most individuals in the super single-modal group expressed their stickiness behaviors to driving, also mentioned as a method to maintain their independence. Their reliance on cars was sometimes inconsistent on special occasions when they could not use their cars for travel; however, the majority of their daily activities were done with their personal vehicles, and they had less positive perceptions about other modes, such as public transit and walking. Along with the semi single-mode group, the super single-mode group mentioned health conditions as another factor that hindered them from walking, as walking to and from stations can be overwhelming. The semi single-mode group similarly relied on private vehicles, as they highlighted that their primary mode of transportation is driving. The majority struggled to lose independence. However, driving can be cost burdening for some individuals. Lacking public transit infrastructure is another reason they cannot use public transit, as well as the accessibility to public transit, inconvenience, and the time-consuming part. Some expressed their interest in other modes, such as biking or public transportation.

As seen in Figure 3.3a, mode use by necessity, not by choice, financial influence, and being adaptive to various modes that work for them was mainly distinct in the multimodal groups. The semi multi-mode and super multi-mode groups both were more open to varying modes. However, they expressed similar concerns with regard to walking to transit. Commuting modes varied from driving to public transit. Driving can be a first choice for those considering time constraints for commuting and grocery shoppers who might have difficulty carrying the shopped goods. One individual (P4) drove but also relied on his family. The super multi-mode group mentioned that public transit is a way to maintain independence and attachment to biking, and public transit was noticeable. They were more flexible and lenient in finding ways to get to places using different and available modes. Daily mode decisions are generally leaned more towards public transportation and diverse options exist, from relying on friends and family to biking.

Single-mode individuals indicated that driving is their way to maintain independence, while the multimodal group thinks public transit is. Walking to transit stops is the biggest concern in terms of taking public transit, and it applies to both single and multimodal groups. Without financial constraints or health-related issues, driving is a primary mode for most individuals.

3.2.2.2 Future Travel Behavior

Figure 3.3b describes that future behaviors of the super single-mode group's voices were depicted as passive and less open to other modes. Many expressed their plans to stick with their current behavior and to rely on their friends and family. However, they were concerned about losing independence. There were opinions of becoming homebound or moving to assisted living homes that do not require traveling. One individual with experience with ride-hailing services mentioned that she would use the service in the future. Although some semi-single-mode groups mentioned that they would keep driving, some expressed interest in other modes, such as paratransit, ride-hailing services, or moving to a more walkable neighborhood. One also mentioned autonomous cars. However, one individual maintained a passive voice, considering work-from-home options, staying home, and having their kids come to see them.

Some participants from the semi multi-mode group showed their strong stickiness to driving, as they explicitly mentioned that "to be able to drive up until the day I die, life would be great." Ride-hailing and relying on friends and family can be an option. However, two interviewees also think of reducing travel frequency. Regarding the super multi-mode group, their future behavior was opened to different modes. They were somewhat, but not fully dependent on, friends and family, and some individuals brought up new modes, such as e-bikes or three-wheel bikes, which require less energy and are safer.

Among single-modal groups, passive voices persisted more than the multimodal groups. The multi-mode group had more varying options to prepare for the future and expressed willingness to change their environment. There were not a lot of experiences in ride-hailing among all groups. However, the one with the ride-hailing experience considered this mode of transportation as a viable option in the future. Reducing travel frequency and stickiness to driving (current drivers) was somewhat prevalent across all the groups.

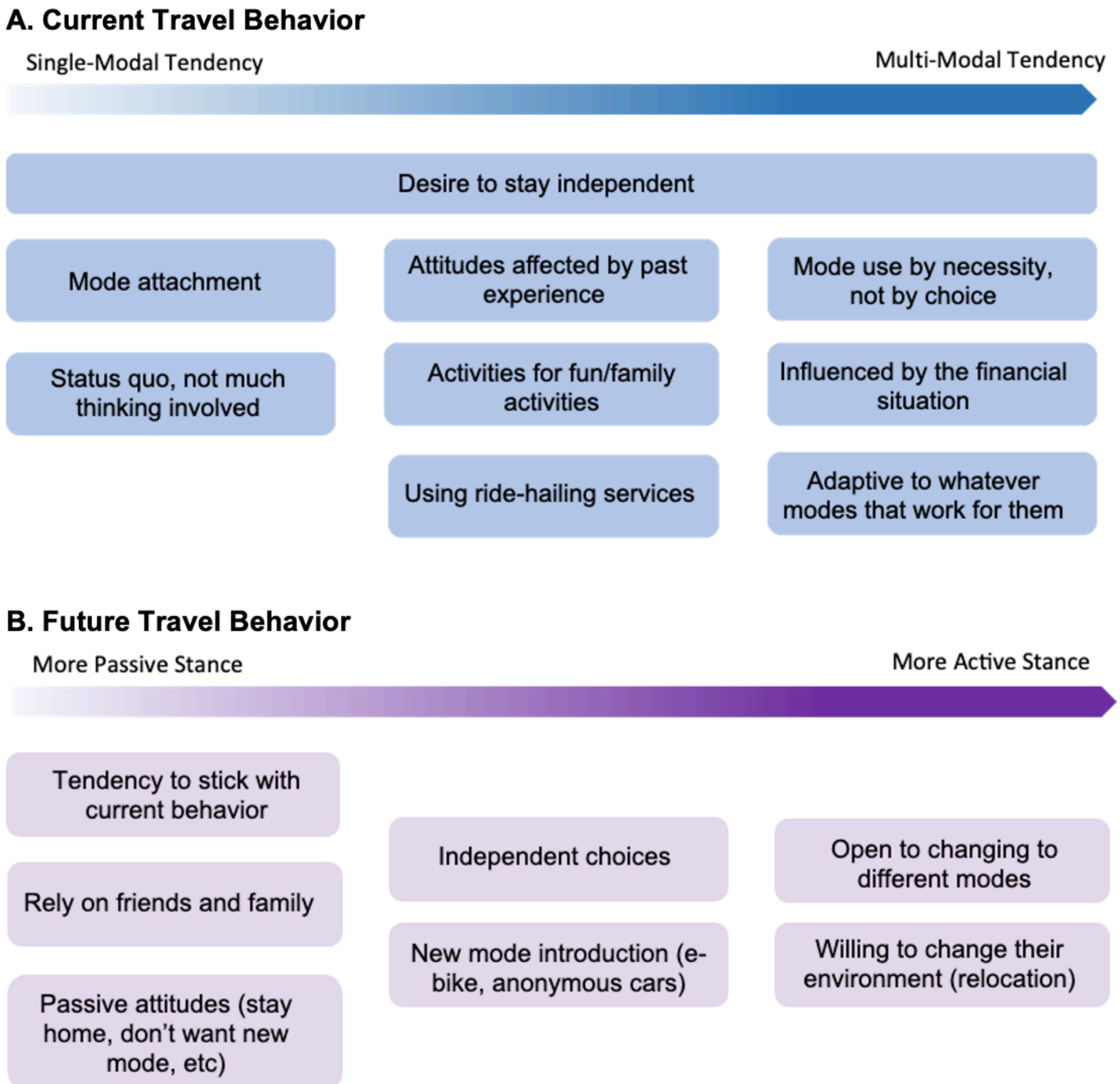


Figure 3.3: Major themes from the current and future travel behavior

3.2.3 Dimensions of Transportation Resources

3.2.3.1 Personal Dimension

Figure 3.4 shows the personal, social, and physical dimensions related to transportation resources. An older adult's personal dimension for transportation consists of functioning, preferences, financial constraints, and motivation. Their functioning is in relation to their physical health and mobility from getting from place to place. There were expressed concerns about walking to and from locations or transit stops due to pain and distance. P9 says, "I like walking, but I can't do it anymore. I just have a terrible time walking." Their preferences are derived from previous experiences and/or lack thereof, which can be well characterized by P6's comment: "To be able to drive up until the day I die, life would be great." Financial constraints were considered when taking any mode, and ride-hailing had the most comments about not being cost effective. Lastly, convenience of transportation was one of the major factors of choosing a certain transportation mode. For example, the time and availability of each mode determined the willingness to take them. This is well captured by P13's comments on aging services: "I used to walk all the time, but like I said, I went for rides for wellness all the time. And I couldn't trust them to be there when I needed them to."

3.2.3.2 Social Dimension

The social dimension of transportation resources, which includes social networks, family support, and social connection, can also influence the travel behavior of older adults. In terms of mobility, whether an older adult has a partner makes a difference. Men and women appear to have different coping mechanisms when it comes to partner loss. It appears that one's social network influences one's travel destination as a social boundary rather than their modal behavior.

The benefit of family support is trust, love, and respect; however, older adults often do not want to be a burden to their family at the same time. P4 says, "You can trust them; they are probably not going to do anything to do you wrong. The cons are that I don't want to, and I'm not putting on that burden. I want them to live their own life. Even though we took care of them, they need not be worried about what I'm doing, to a point." P2 also shared the same idea: "And it's pleasurable to be with people you love and respect. But then I'd get a feeling of being a burden. And I wouldn't want to bother people." As well as family support, P4 also highlights the importance of social networks if family support is not feasible. "It depends on, just on your situation. Suppose you have a good family support system that can take on some of the burdens. Then you're miles ahead. There are folks that don't for whatever reason. You have to do even more planning or hope you have the resources. I mean, if you have the resources, we could get around some of this stuff."

3.2.3.3 Physical Dimension

3.2.3.3.1 Perception of Physical Environment/Resources

Perception about the current environment drives people's behavior and affects future mobility decisions. Two individuals, P12 with low perception and P13 with high perception, were compared to analyze the perceived physical environment and resources. P12 has various experiences in public transit systems worldwide and usually adopts multiple modes. Compared to her experiences outside the States, such as in Hong Kong and London, where she lives now is perceived as "isolated," and the lack of service or resources stops her from using public transportation. Therefore, she can be described as an individual with a lower perception of the environment. "All these recreation things you drive. So even if you go to the bus station, I have to drive to ..." depicts P12’s frustration with the isolation from public transit systems. However, her past experiences influenced her to choose public transit in the future, and even relocate to make better use of the system when she can no longer drive.

P13 explicitly reveals her positive perception of the public transportation system in Utah by saying, “When I came back to Utah from Arizona, I had to learn the bus system here. And I absolutely loved it." Her enjoyable experiences in public transit, such as interaction with different people, helped her formulate a high perception and motivated her to continue using the mode in the future. Although she has difficulty walking and uses assistive devices to help her walk, she showed her stickiness to public transit. She is also open to trying new modes and will use mobility aids to continue using public transit. Her situations imply that some people have grown to like public transit because it provides opportunities for social interaction.

When the effect of the physical environment is large enough, the built environment dominates people’s behavior, as seen in P12’s case. P12 had a lower perception of the current built environment towards public transit, which stopped her from utilizing public transit, although she had a positive experience in the past outside the country. However, when the effect of the physical environment is relatively small, other factors such as perception, motivation, and previous experience tend to influence behaviors. P13 has difficulty walking to and from transit stops and requires assistive devices, but her positive experiences motivate her to persist in using public transit.

3.2.3.3.2 Actual Physical Environment/Resources

In comparing the actual physical environment and resources, two individuals were compared; P16 lived in a highly walkable neighborhood with easy access to public transit, and P11 lived in a low walkable neighborhood with lower public transit access. Those participants were selected by looking at their physical address, and the number of transit stops within a designated boundary. P16 frequently uses medical insurance rides for his doctor’s appointments, shuttles to the hospitals, and public transit systems. He mentioned that he had knee surgeries and did not drive anymore. He is also experiencing financial burdens, and that affected him to choose public transit as his primary mode of travel.

P11 is living in a transit desert with no option but to drive. Accordingly, he shows the influence of the built environment to travel behaviors. The built environment can significantly influence people’s travel mode choices.

However, what really impacts them is their perception, situation, motivation, and personal needs or preferences collectively.

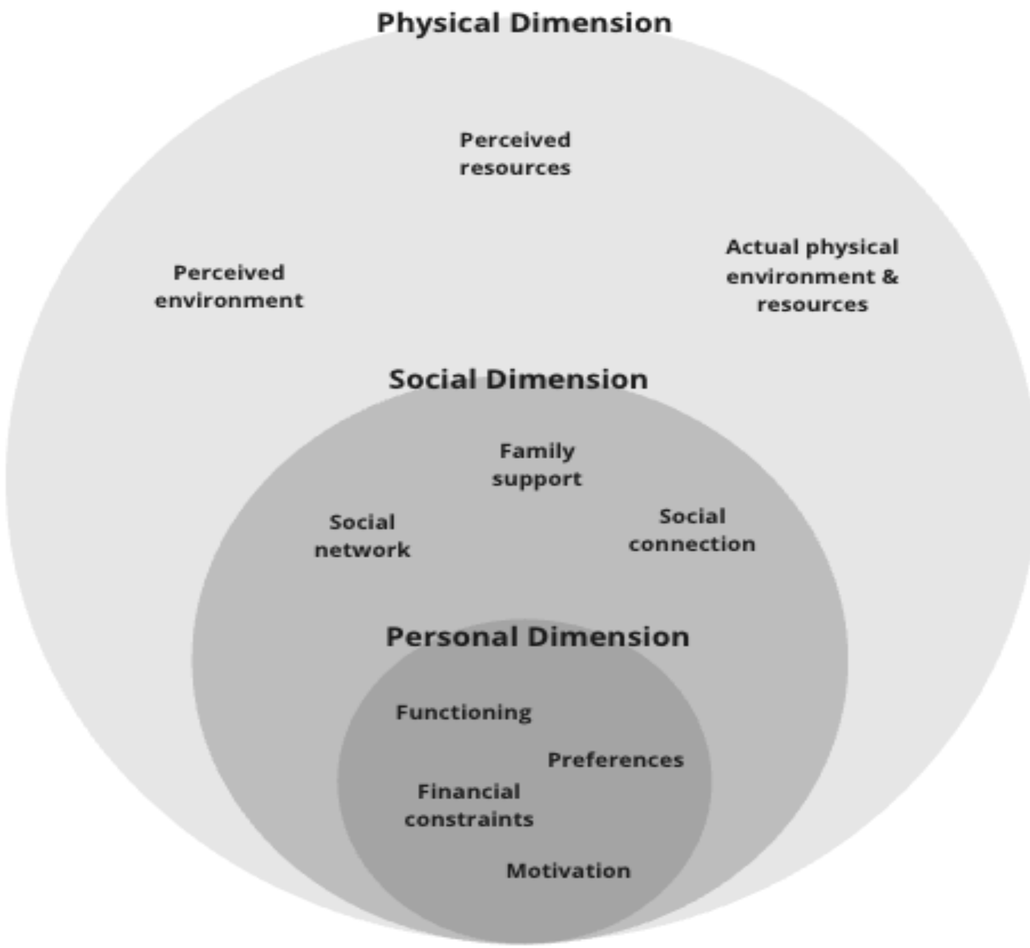


Figure 3.4: Dimensions of transportation resources

3.2.4 Discussion

3.2.4.1 Spectrum of Travel Behaviors

In our research, older adults' current modal behavior was shaped by social and personal factors, such as the desire to stay independent, current mode attachment, attitudes affected by the experience, mode use by necessity, status quo of the surrounding situations, fun/family activities (special occasions), financial situation, and ability to adapt to different modes. Hanson (2010) and Schwanen et al. (2008) found that older adults' transportation choices are influenced by different factors, such as their social relationships, the environment they live in, policies and regulations related to transportation, and cultural norms and expectations surrounding mobility. Social and cultural contexts interact to form current travel behaviors. Among all groups, the desire to stay independent remained strong—however, their mode choice and multi-mobility varied by their day-to-day patterns. Single-modal groups tended to reveal mode attachment to cars, and multimodal groups showed higher adaptability to modes that work for them.

Future transportation behavior varied by personal attitudes towards different modes and their stance in making mode choices. Single and semi single-modal groups revealed passive voices; conversely, the super multimodal group was more open to different mode choices in making future mode decisions. Musselwhite (2018) found that older adults maintain a strong attachment to driving which signifies a sense of belonging to society, and giving up driving meant losing that sense of belonging. As driving is a bridge connecting older adults to society, it seemed difficult for them to stop driving and find alternative modes. For that reason, some individuals in the single-modal groups indicated that they would decrease travel frequencies and stay home when they are in the stage where they cannot drive. Conversely, multimodal groups showed a more active and positive stance to alternative mode choices. Those who currently use various transportation modes tended to extend their options as they age in the future, and fewer individuals showed passive stances.

3.2.4.2 Dimensions of Travel Behavior and Resources

In terms of the social-ecological model of travel behavior, our results are consistent with the findings of previous literature (Hough et al., 2008). The model further explains each of the dimensions and how they could impact a person's travel behavior through unmet travel needs (Luiu et al., 2017). Below are in-depth explanations of each component of the ecological model.

3.2.4.2.1 Personal Dimension

As shown in Figure 3.3, the personal dimension of an individual's travel behavior influences their overall health, functioning, financial, and demographic status. As people age, their physical mobility decreases their ability to walk, drive, use transit, and bike. This alone brings dissatisfaction to all modes of transportation for older adults who experience difficulty with their health and functioning (Nordbakke & Schwanen, 2015). In our study, we found that functioning influences people's modal behavior and social activities; however, the functional limitation does not entirely limit one's modal behavior. Personal preference and willpower can make a difference in terms of how they seek other opportunities for travel, so a difference in mentality/attitudes can affect their behavior and also their future prospects (especially with public transit). In addition to a person's diagnosed health and mobility, each individual has a self-perceived health (Nordbakke & Schwanen, 2015) that contributes to their capability and satisfaction for mobility and transportation (Nordbakke & Schwanen, 2014). The individual's physical location, as well as their cognitive processes, can impact their travel behavior due to both their perception of the environment and their travel behavior intentions (Spears et al., 2013). Their cognitive ability can assist in their judgment while decision-making on the mode choice, and their physical location can provide or exclude additional options (Tolmie & Thomson, 2003).

An individual's income is an important factor of one's travel behavior as they are more likely to take the mode that is cost effective given their financial situation (De Vos, 2022). Our findings show that financial constraints play a large role in influencing an individual's mode choice. People with financial constraints tend to rely on public transit and paratransit. It limits their freedom to choose other means of transportation. People who use public transit can also find a way to get to places. They have higher adaptability and resilience as they seem to make the switch to more convenient means of transportation.

Demographic status is another predictor of travel behavior as a person's age, gender, ethnicity, and living circumstances can affect their availability and capability to take different modes of transportation (Nordbakke & Schwanen, 2015). A couple of widowed adults were interviewed in our focus group and showed less likelihood to take different modes than those who were single or married. In terms of the travel behavior of widowed individuals, there is a gender difference. Women tend to have stronger coping mechanisms than men when they lose their partner (Shye et al., 1995). Women tend to maintain their social activities and behaviors even after they lose their partners.

3.2.4.2.2 Social Dimension

An older adult's social network can influence their travel behavior as they may need to rely on other people to get around (Al-Rashid et al., 2022). Our findings show that some people have grown to like public transit because it provides opportunities for social interaction. Social networks appear to influence people's travel destinations (social boundary) (Figure 3.3), not so much their modal behaviors. Most modes of transportation have a potential for social interactions unless the individual is driving solo in their own automobile. For example, public transit holds a diverse range of community members, creating a social opportunity for transit users. P13 from our study mentioned the enjoyment felt by conversing with new people when taking transit. Independence is a consistent value for older adults, but they may need to be residing near or with someone who can help them get to a destination if they are no longer able to do it themselves, especially if they want to continue living in the community (Graham et al., 2020). Additionally, social norms and habits can contribute to an individual's perception of each travel modal behavior (Spears et al., 2013).

3.2.4.2.3 Physical Dimension

The physical dimension of the transportation resources is diverged by the perception of the physical environment and the actual physical environment. Individuals' perceptions, followed by their expectations, tend to change their travel behavior. Clarke and Gallagher (2013) found that the perceived safety and the built environment affect older adults' outdoor mobility. In other words, safer and more accessible environments influence older adults' travel frequency. Interestingly, one individual in the focus group has grown to like public transit because it provides opportunities for social interaction. We also observed that when the impact of the physical environment is relatively small, other factors tend to influence travel behavior, such as perception, motivation, previous experience, etc. For instance, a study by Kitamura, Mokhtarian, and Daidet (1997) found that attitudes toward the built environment and transportation accessibility are strongly associated with trip making. These findings suggest that interventions to change travel behavior should consider various factors, including physical environment, perception, motivation, and previous experience.

Our results also indicate that social network can address the gap between the personal dimension and the physical dimension. If someone wants to travel more but their physical environment is not supportive, then they rely on families and friends to get around. Depending on the level of their social network, some people may be able to address this gap and some people may not be able to. As previously mentioned, social networks are different between genders and their abilities to cope with transportation barriers. Men with smaller social networks tend to face more health issues and higher mortality rates compared to women with small social networks (Shye et al., 1995). In our study, we noticed that widowed men are less likely to leave their homes or use public transportation services.

3.3 ACCESSIBILITY OF OLDER ADULTS

This section presents the results of the accessibility study of older adults. The framework of the accessibility study is shown in Figure 3.5.

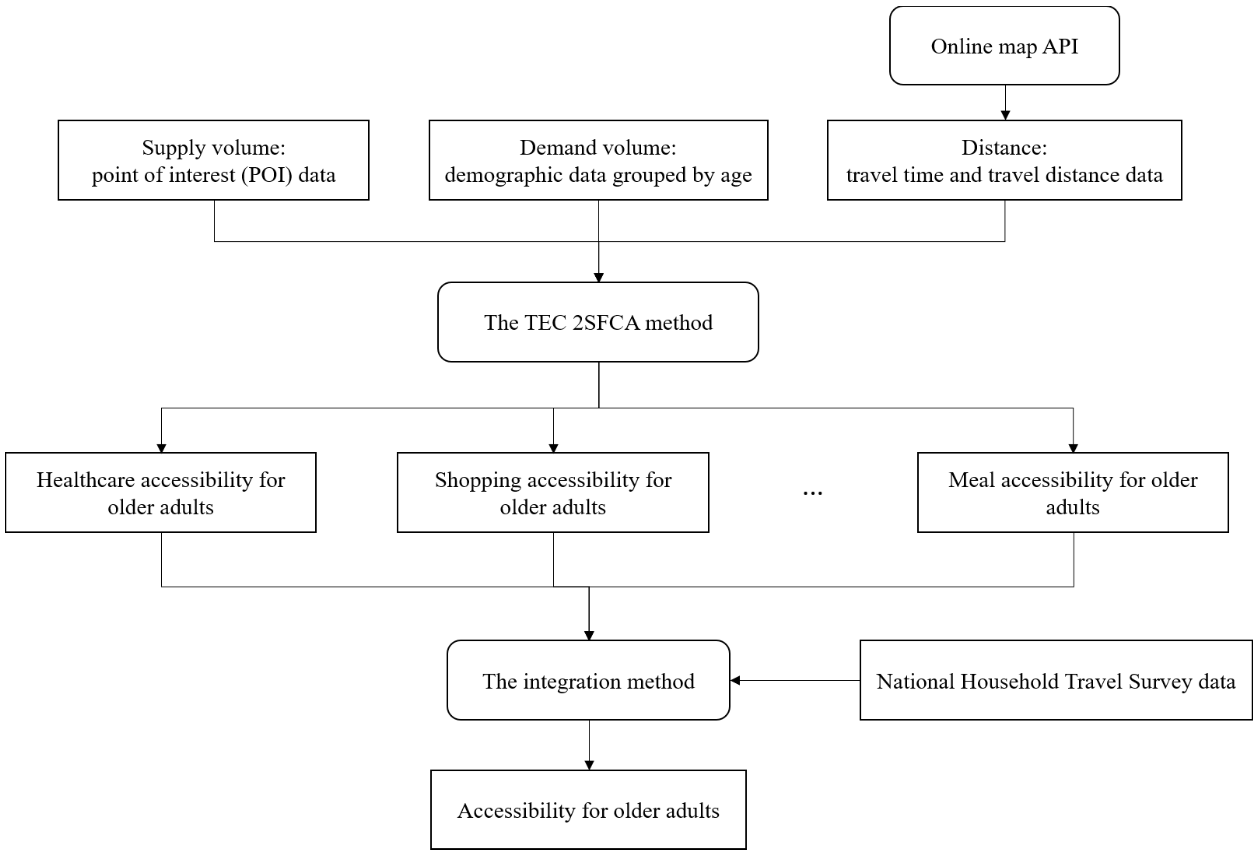


Figure 3.5: Flowchart illustrating how accessibility for older adults was measured

The study area is Salt Lake County, Utah's most populous county. As of the 2020 U.S. Census, the population is 1.186 million, and 11.6% are older adults (65 years and older). The county is divided into 22 municipalities and 251 census tracts. As depicted in Figure 3.6, the municipalities are primarily concentrated in the central region, while the eastern and western regions are predominately suburban.

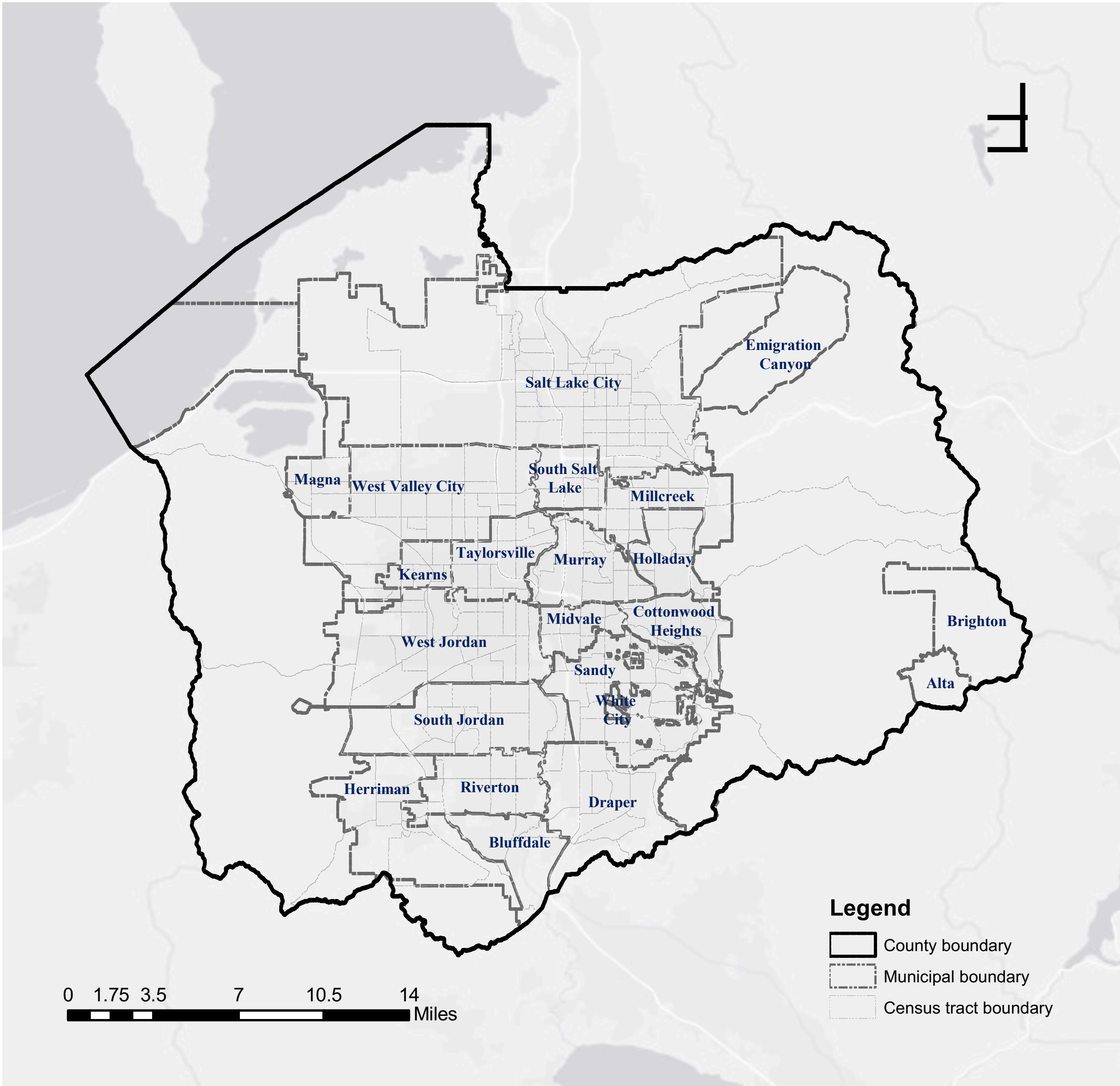
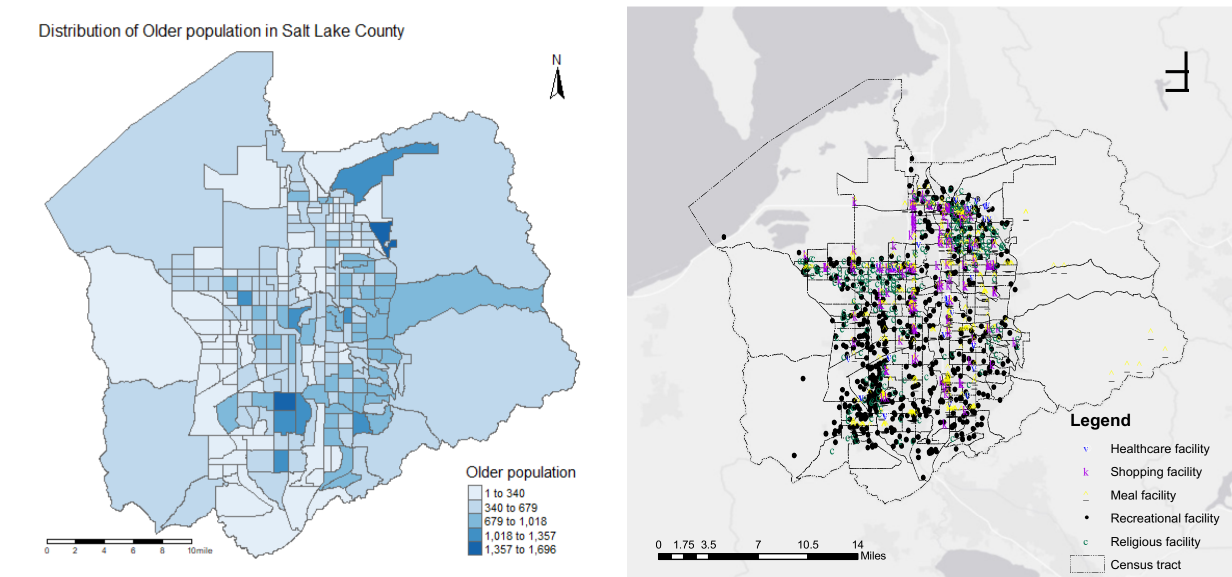


Figure 3.6: Spatial distribution of administrative districts in Salt Lake County

In the case study, we extracted travel frequency, spatial impedance, demand, and supply from multiple data sources. First, we relied on the 2017 National Household Travel Survey (NHTS) data for identifying trip purposes. The data were grouped by older adults' trip destination purpose to identify the categories of activities and gauge the frequency of older adults attending those activities. The most frequent trips older adults made and corresponding frequencies are shown in Table 3.6. Some trips with smaller proportions, such as school attendance (0.0774%) and childcare (0.0840%), were not essential activities for older adults, and thus were excluded. The travel time and travel distance were estimated using Google Maps API. The threshold travel times are set based on a real-world travel time matrix. Table 3.6 depicts the threshold travel times for all types of facilities.

Basic characteristics of older adults were obtained using age-specific demographic data gathered from the U.S. Census Bureau. Figure 3.7 (a) depicts the distribution of the older population in Salt Lake County. Facilities' locations served as supply points, while their areas provided supply volumes. Service facilities were selected as they were frequently visited by and important to older adults (Chen et al., 2020; Engels et al., 2011). The facilities were extracted using osm2gmns in accordance with the activity categorization. The osm2gmns is an open-source Python package that can collect POI data from OpenStreetMap, including geographic information, facility area, and the number of facilities. The distribution of facilities is shown in Figure 3.7 (b).



(a) (b)

Figure 3.7: Distribution of older population (a) and facilities (b) in Salt Lake County

According to the 2012 Utah Household Travel Survey, trips made by private automobile account for 90.9% of all journeys of older adults in Salt Lake County. Additionally, previous studies suggest that the most common travel mode for older Americans is private automobiles (Wasfi et al., 2012). Therefore, our study used car driving as the primary mode of transportation. Accordingly, we used the value 0.48 for b in generalized time function to indicate the car as the primary mode (American Automobile Association, 2022).

Table 3.6: Trip Frequency of Different Activities

Activities	NHTS trip destination purpose	Frequency	Weight	Threshold travel time (min)
Shopping	Buy goods (groceries, clothes, appliances, gas)	19.16%	51.84%	8

Meals	Buy meals (go out for a meal, snack, carry-out)	8.12%	21.97%	8
Recreation	Recreational activities (visit parks, movies, bars, museums)	3.02%	8.17%	7
Healthcare	Healthcare visit (medical, dental, therapy)	2.91%	7.87%	13
Religion	Religious or other community activities	3.75%	10.14%	10

3.3.1 The Accessibility of Different Service Facilities

To identify the differences in accessibility spatially, a quintile method was applied to separate the accessibility scores into five classes. Figure. 3.8(a) shows the spatial distribution of accessibility to healthcare services for older adults, which was obtained using the TC 2SFCA method. The black dots in the diagram represent service facilities. First, the lower accessibility of the eastern and western suburbs reveals that it costs more for suburban residents to access healthcare facilities than urban residents (Luo et al., 2009). Second, the marked regions show high accessibility. Region 1, located in Salt Lake City, is home to numerous hospitals, such as the University of Utah Hospital and LDS Hospital. Region 2 is mainly situated in Murry, with comprehensive medical facilities like Intermountain Medical Center. Region 3 is made up of the municipalities of West Jordan, South Jordan, Riverton, and Herriman, each of which has healthcare facilities. Regions 1, 2, and 3 have 10, 10, and eight hospitals, respectively, accounting for 25%, 25%, and 20% of the total. The fact that tracts closer to facilities are easier to access services is consistent with the fundamental assumption of spatial accessibility. It is worth noting that Region 3 is more extensive than Regions 1 and 2, which may be because more decentralized medical facilities are able to provide greater service capacity than centrally distributed medical facilities.

To demonstrate the merits of the TC 2SFCA method, we compared the TC 2SFCA results with results using the commonly used Gaussian 2SFCA (Fransen et al., 2015; Chen et al., 2021). Figure.3.8(b) shows the spatial distribution of healthcare accessibility based on Gaussian 2SFCA. As shown in Figure 3.8(a) and (b), these two approaches yield broadly consistent distributions of accessibility, indicating that TC 2SFCA can effectively identify geographical disparities in accessibility. A more precise spatial distribution is measured by TC 2SFCA as it considers more factors in older adults' accessibility analysis. In the middle of Region 3, several tracts were in a different classification from the surrounding tracts in terms of accessibility. The surrounding tracts have access to healthcare facilities close to home and those farther away, while the middle tracts have moderate distances to each nearby facility, so their accessibility scores are similar when merely considering distance. After incorporating cost, older residents with financial limits in surrounding tracts might still be willing to travel because they can choose to access healthcare facilities close to home with the least cost. However, it will cost more if those living in middle tracts decide to travel. Therefore, their travel demands will decrease. These finer variations are exactly what we aim to capture when measuring the accessibility of older adults. Figure. 3.8(c) shows the ratio of the accessibility measured by Gaussian 2SFCA and TC 2SFCA methods (called accessibility inflation factor). In most census tracts, the accessibility scores based on Gaussian 2SFCA are three times higher than that based on TC 2SFCA, proving that TC 2SFCA can overcome the overestimation issue. Some suburban tracts have particularly large accessibility inflation factors. Because suburban areas have fewer cars, better road conditions and no traffic jams, the travel time from suburbs to facilities is not much greater than that in urban areas, even if they are far from the facilities. However, the considerable distance will lead to more cost. Therefore, merely considering time would overestimate the accessibility for older adults living in the suburbs.

We also measured accessibility by setting the threshold travel time to 30 minutes, which is the recommended travel time to healthcare facilities (Chen et al., 2021; Wei et al., 2013). As shown in Figure. 3.8(d), tracts located in the middle of Salt Lake County showed high accessibility because older adults are able to access most of the medical facilities with relative ease. The lower-left and upper-right areas show relatively low accessibility due to the distance between them, making it more difficult to pass between them. However, their accessibility scores mainly range from 12 to 15, which is not much less than the high accessibility scores. Tracts with accessibility greater than 10 account for 96.8% of the total. Further, we used the coefficient of variance (CV), which is defined as the standard deviation of an indicator divided by its mean, to analyze the differences in accessibility. The smaller the value of CV, the smaller the difference in spatial accessibility among census tracts. The CVs of accessibility in Figure 3.8(d) and (a) were, respectively, 0.202 and 1.196. When the threshold time is set as 30 minutes each tract can access most medical facilities, so the difference in spatial accessibility among census tracts is extraordinarily slight. These accessibility scores can hardly reflect the spatial differences as the catchment area has lost its significance. Therefore, we should set a reasonable catchment area according to local situations. It is worth noting that people may be willing to spend more than 30 minutes traveling to a healthcare facility when there are no better options, but our study is to capture relative differences in spatial accessibility.

By introducing a time and cost-based decay function, the TC 2SFCA method fully considers the availability, sustainability, and affordability of older adults to identify finer differences in accessibility among demand points. In addition, it sets the catchment area according to the actual local travel time, which can effectively avoid wrongly measuring the accessibility by setting an inappropriate threshold time. Thus, the TC 2SFCA method produces more accurate and robust results than traditional approaches.

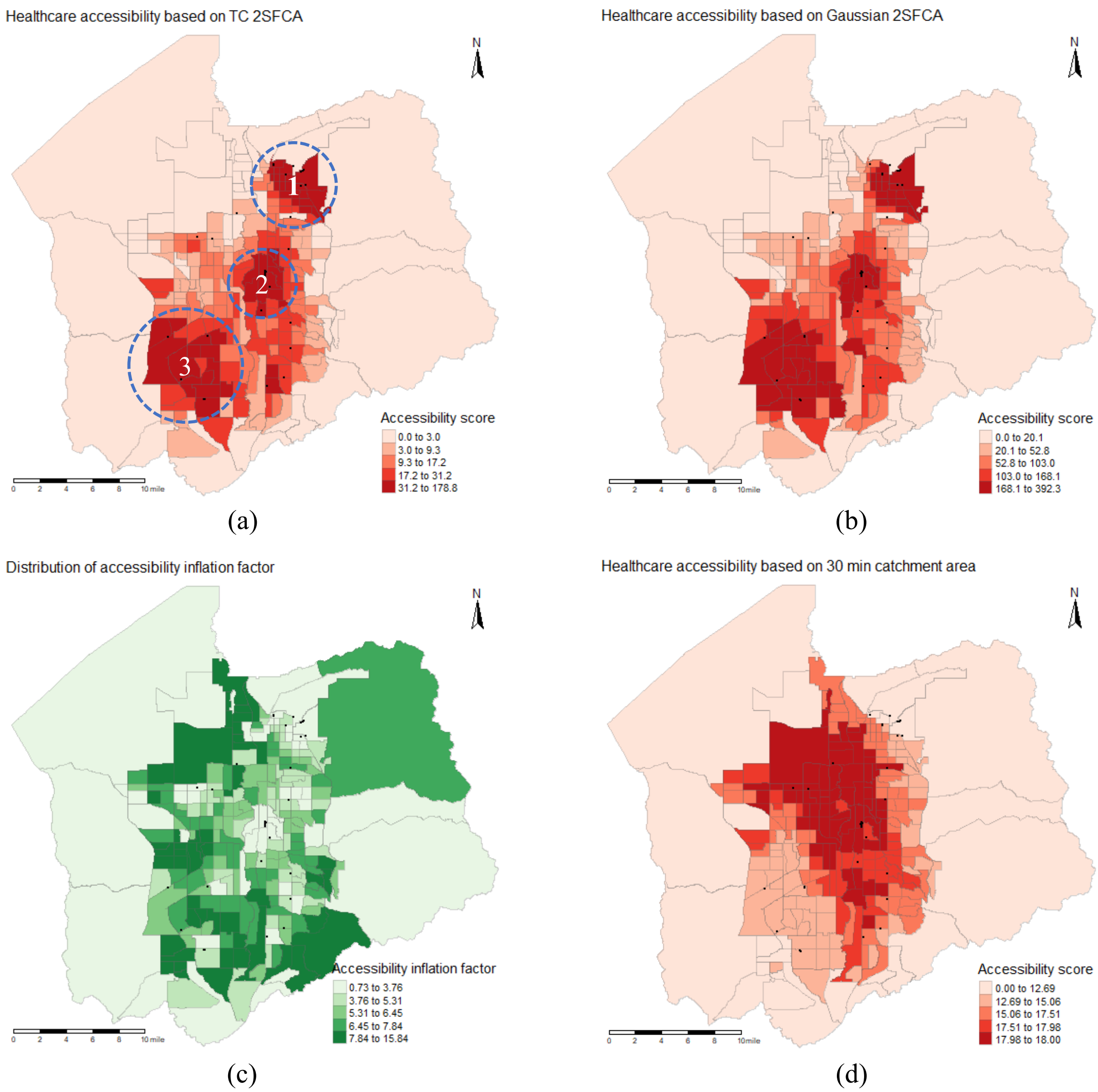


Figure 3.8: Comparison between different methods of healthcare accessibility; (a) the distribution of healthcare accessibility based on TC 2SFCA; (b) the distribution of healthcare accessibility based on Gaussian 2SFCA; (c) the ratio of the accessibility measured by Gaussian 2SFCA and TC 2SFCA methods; (d) the distribution of healthcare accessibility based on the 30-minute catchment area

As shown in Figure 3.9 (a), most shopping resources are concentrated in Salt Lake City and Murray. This means that older adults living there have higher shopping accessibility. Although shopping resources are relatively low overall, some tracts in the lower part of Salt Lake County remain highly accessible, probably because of the high supply-to-demand ratio within the catchment areas. In these areas, demand density is 30% lower than the total average, while facility capacity is 48% higher. That means the few large shopping centers in these areas have been able to meet the shopping needs of older adults. Figure 3.9 (b) and (c) show the distributions of meals and recreation accessibility are spatially even, indicating that most older adults in Salt Lake County can meet their demands for meals and recreation. As of 2020, 60.68% of Utahns are reported as members of The Church of Jesus Christ of Latter-day Saints. There is a large religious activity demand among older adults in Salt Lake County. Figure 3.9 (d) shows that Salt Lake City and West Valley City are more accessible to religious facilities.

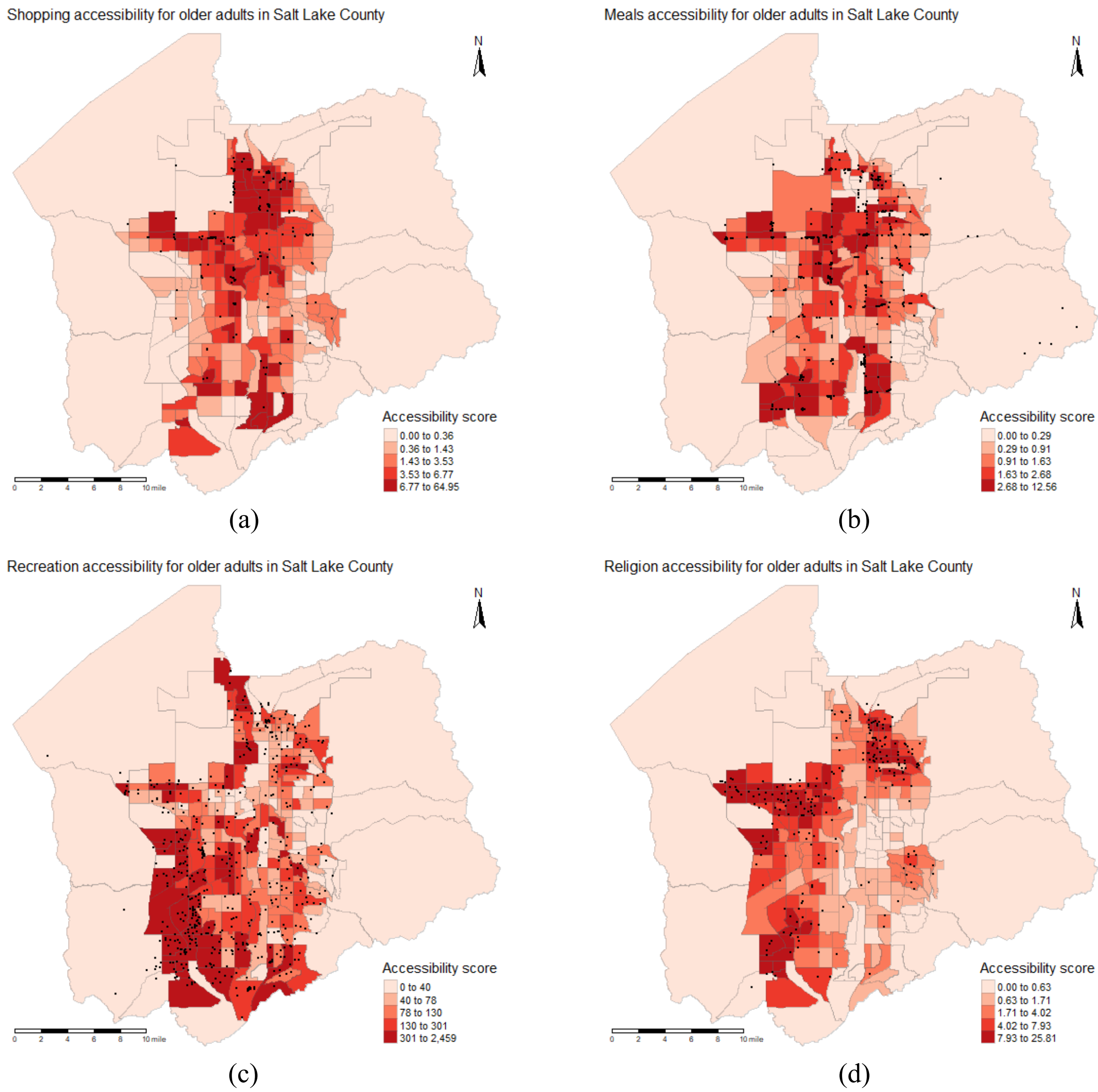


Figure 3.9: The distribution of (a) shopping, (b) meals, (c) recreation, and (d) religion accessibility for older adults

3.3.2 The Integrated Accessibility

Figure 3.10 (a) shows the distribution of integrated accessibility based on TC 2SFCA. Overall, metropolitan areas have better accessibility for older adults than eastern and western suburbs. The tracts with high accessibility are located in Salt Lake City, South Salt Lake, South Jordan, Riverton, Herriman, and Draper. To justify this method, we compared it with the improved cumulative opportunity measure (Chen et al., 2022), which assessed accessibility to service facilities for older people in age-restricted communities. Specifically, the improved cumulative opportunity method first calculates the number of one type of facility (opportunities) within the threshold time as the accessibility of that type of facility. After normalizing the accessibility of each type of facility, the integrated accessibility is calculated as the average of the accessibility of all types of facilities. Census tracts and 10 minutes (the average threshold travel times for various facilities) were used as demand points and threshold travel time for the cumulative opportunity approach.

Figure 3.10 (b) shows the distribution of integrated accessibility based on cumulative opportunity. The disparities between Figure 3.10 (a) and (b) are mainly reflected in the lower part (highlighted in black) of Salt Lake County. This may be due to the lower part's low population density, despite its relatively few facilities. The average number of opportunities and population of the lower part are 205 and 400, compared to 199 and 496 for the whole region. The supply capacity in the lower part is slightly higher than the average supply capacity, while the demand density is 20% lower. For further analysis, we explored the relationship between integrated accessibility based on TC 2SFCA and opportunities per person.

The distributions of their natural logarithms are plotted in Figure 3.10 (c). The statistical significance of the regression is reasonable, and the fit follows a power function $y = 0.611x^{0.759}$, where y is opportunities per person and x is accessibility. When an area's accessibility is low, the accessible resources per person are insufficient. As accessibility increases, resources per person increase significantly. However, when accessibility reaches a certain level, further improvements in accessibility do not raise resources per person to a corresponding extent because resources are always limited in reality. In contrast to the cumulative opportunity approach, the method proposed in this study can effectively reflect the resources available to each older individual because it incorporates supply, demand, and their relationship. As stated in the introduction, a facility may not be available to older adults even though it might be physically accessible, as its service capacity is limited. Accessibility measures that consider multiple factors are more realistic.

Additionally, the improved cumulative opportunity method weighs each type of facility equally, with the assumption that older adults would value accessibility to all facilities equally. Yet, in reality, older adults may place a higher priority on facilities that are frequently utilized (Chen et al., 2020; Engels et al., 2011). Figure 3.10 (d) displays the updated distribution of integrated accessibility based on TC 2SFCA with equal weights to all facilities. The green-highlighted regions in Figure 3.10 (d) are those with higher accessibility for recreation and religion, whereas the yellow-highlighted regions are those with greater accessibility for shopping. The accessibility integration method in this study allocates a greater weight to shopping accessibility and a lighter weight to recreation and religious accessibility based on how frequently older adults engage in those activities. Assigning larger weights to more critical or frequently used facilities is more reasonable and realistic.

Overall, the integrated accessibility in this study reveals the resources available per person in each tract by incorporating the demand, supply, and their relationship. Moreover, the difference in older adults' demands for each type of facility was considered by including trip frequency. Therefore, the integrated accessibility based on TC 2SFCA can identify places with resource shortages for older individuals more correctly and realistically than traditional measures.

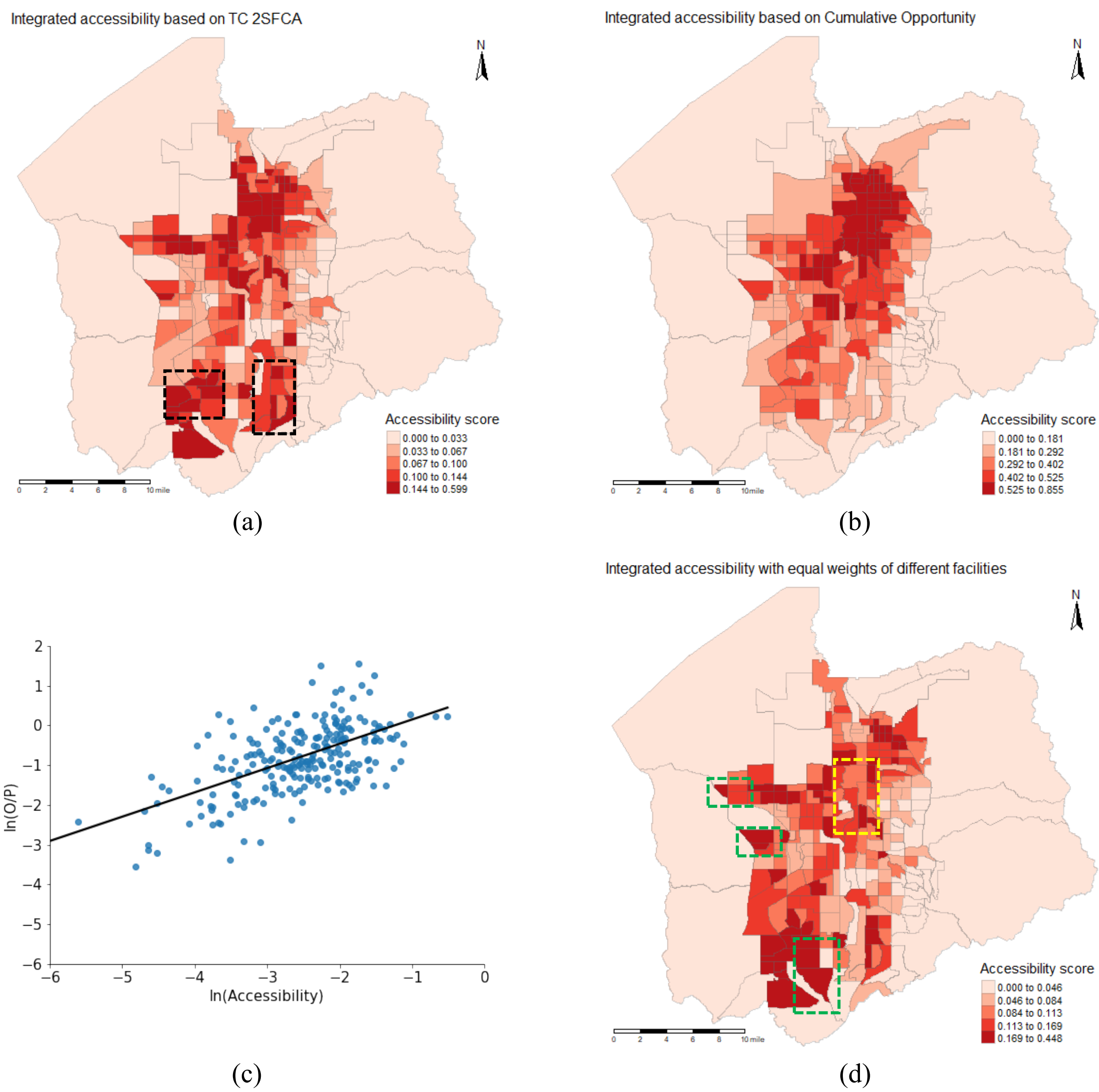
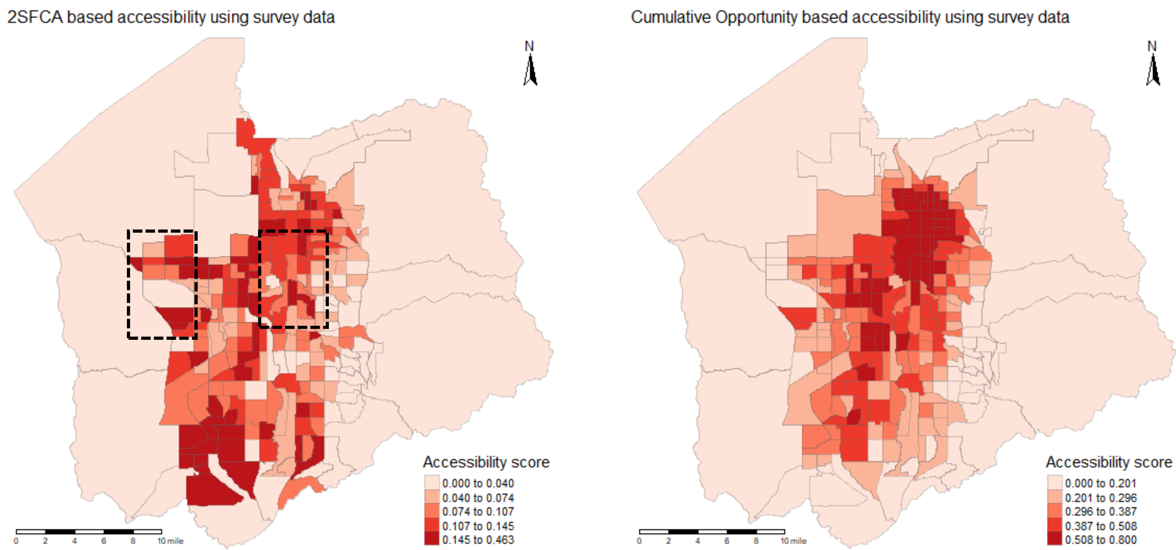


Figure 3.10: An integrated accessibility with NHTS data; (a) the distribution of integrated accessibility based on TC 2SFCA; (b) the distribution of integrated accessibility based on cumulative opportunity; (c) relationship between accessibility and accessible opportunities per person; (d) the distribution of integrated accessibility with equal weights of different facilities.

We further integrated the survey data to calculate the accessibility score. First, we obtained the frequency of travel by activity for Utah older adults, which is shown in Table 3.7. The accessibility distributions using survey data are shown in Figure 3.11. Comparing the distribution of accessibility using NHTS data with our survey data, the main differences are as follows. Using the survey data, the accessibility of the west side of the map has increased. This may be due to an increased weight of religion and recreation accessibility, which increased by about 25% and 400%, respectively. Well-being and quality of life can be achieved through older adults devoting more time to actions and tasks related to community life, recreation, leisure, religion, and spirituality, and spending time with family and friends (Herzog et al., 2002). Participation and leisure activities contribute to successful and healthy aging (Dahan-Oliel et al., 2010). This translates well with higher demand for religious and recreational activities among older adults. With the survey data, accessibility of the center of the map has decreased, driven by a decrease in the weight of shopping accessibility, which decreases by about 54%. The decrease in the shopping accessibility weight might be due to the increase in the weight of other activities. Using the trip frequency of the survey data for weighting, the cumulative opportunity-based accessibility does not vary much because the new weights do not vary much compared to the equivalent weights.

Table 3.7: Trip Frequency of Different Activities Based on Survey Data

Activities	**Frequency**	**Weight**
Shopping	16.23%	23.62%
Meals	15.57%	22.66%
Recreation	21.91%	31.88%
Healthcare	6.29%	9.15%
Religion	8.72%	12.69%



(a) (b)

Figure 3.11: An integrated accessibility with survey data; (a) the 2SFCA-based accessibility using survey data; (b) the cumulative opportunity-based accessibility using survey

3.3.3 Discussion

We developed an adjusted 2SFCA method with a decay function incorporating time and cost to measure the accessibility to different service facilities for older adults, accounting for the availability, sustainability, and affordability that older adults would consider when traveling. Compared with Gaussian 2SFCA, TC 2SFCA can overcome the overestimation issue, identify finer spatial differences in accessibility, and provide a more accurate assessment of suburban accessibility. To sum up, the TC 2SFCA method is more suitable for measuring accessibility for older adults.

A dynamic data collection pipeline based on Google Maps Distance Matrix API was developed to estimate travel time and distances. Unlike most prior methods that relied on road travel speeds, our method is more accurate, reliable, and easier to calculate. In addition, we set the catchment area according to the actual local travel time. In contrast to the recommended travel time, the threshold time in this study enables a more reasonable identification of relative differences in accessibility among tracts. The pipeline framework and the local threshold travel time calculation can be widely generalizable to other regions.

An integration method based on the frequency of older adults accessing those facilities seems to provide a more comprehensive accessibility indicator. The results show the resources available per person in each tract and the significance of different facilities for older adults. Compared to cumulative opportunity measures that only consider the supply side, the integrated accessibility in this study can identify places with competing demands for older individuals more correctly and realistically.

In this case study conducted in Salt Lake County, our findings indicate that for the majority of older adults who are still driving, mobility is a greater concern than accessibility. Interestingly, accessibility to traditionally less accessible areas, such as West Valley and the southern part of the study area, is higher among the older adult population. This can be attributed to the fact that older adults dominantly engage in non-work-related travel, and their preferred activities differ from those of the general population. Moreover, it is important to recognize that for older adults, neighborhood accessibility holds greater significance than regional accessibility.

While the overall results might suggest that current accessibility is sufficient and not a primary concern for older adults, it is crucial to acknowledge that these findings are based on a sample of relatively healthy older adults who still drive. However, it is noteworthy that older adults in the oldest stage (people aged 85+) place great importance on their ability to drive. For individuals who rely on non-car travel modes, have low income, possess a disability, or are medically vulnerable, accessibility becomes significantly more crucial. Therefore, there is a need for further development of accessibility measures and policy interventions that cater to the unique demands of these specific populations. Furthermore, it is important to note that the model used in this study does not incorporate social activities, such as meeting family or friends, due to the challenges associated with establishing specific locations on the supply side. As there are no designated facilities for social and political activities, these aspects were not considered in the analysis.

4.0 CONCLUSIONS

This study provides evidence that older individuals exhibit diversity in their travel behaviors, influenced by factors such as age, income, health, mobility, and the built environment. Our research specifically targeted non-hospitalized older individuals, resulting in a sample of older adults in the oldest stage, with limited mobility, who expressed considerable dissatisfaction with their travel experiences. It is important to note that travel satisfaction is closely tied to health status and the use of assistive devices. Furthermore, we observed a positive relationship between travel frequency and travel satisfaction up to a certain threshold, beyond which satisfaction declined. Exploring the threshold for behavior change in older adults, particularly considering health-related issues and travel fatigue, warrants further investigation. Such studies would help address the travel demands of older individuals and inform policy development tailored to the needs of older adults.

While the majority of older adults rely on driving as their primary mode of transportation, our focus groups also confirmed that it is crucial to pay attention to specific groups with low income, disabilities, and those in the oldest stage, understanding their unique travel behaviors and diverse needs. Travel behavior and accessibility are influenced by personal, social, and physical dimensions. Among these dimensions, personal and social factors have a stronger influence on older adults' decision to travel. However, all three dimensions affect older adults' travel behavior collectively.

Measuring accessibility often focuses on physical dimensions; however, as evidenced in our research, social and personal dimensions also significantly impact travel behavior and accessibility. By employing the 2SFCA method and incorporating survey data, we integrated the demand side of travel accessibility, which inherently incorporated social and personal dimensions. Older adults have distinct preferences for activities that differ from those of younger adults, and their preferred activities possess specific characteristics and time flexibility, unlike work or education-related trips. Our study provides an accurate and realistic measurement of accessibility to major service facilities for older adults. The distribution patterns of accessibility highlight communities that lack or have limited options for specific types of facilities, inspiring strategies to reconfigure the distribution networks of service facilities. These strategies aim to deliver services more equitably and efficiently, ensuring resource equity for older adults. The methodological framework developed in this study is highly adaptable and can be applied to other regions to assess and analyze mobility and resource access equity among older adults.

Accessibility for older adults should encompass diverse dimensions of needs and preferences. Our findings emphasize the importance of considering multiple factors that influence older adults' travel when assessing accessibility. For example, even if the travel time is relatively short, older individuals with limited financial resources may choose not to visit a facility due to the associated costs. Our focus was on older adults who drive, considering the high percentage of car usage among older adults in Salt Lake County (90.9%). However, we acknowledge that there are other older individuals who can no longer drive due to declining health conditions or other financial constraints. Accessibility requirements for non-driving older adults may significantly differ from those who can drive. Therefore, it is crucial to develop distinct accessibility measures for underrepresented groups, such as those with low income, disabilities, and those in the oldest stage, to support their independence in later life. Additionally, future research should consider the accessibility of multiple modes of travel for older adults.

5.0 REFERENCES

American Automobile Association. (2018). Your driving costs. Retrieved from https://newsroom.aaa.com/auto/your-driving-costs/

Ajzen, I. (2020). The theory of planned behavior: Frequently asked questions. *Human Behavior and Emerging Technologies*, *2*(4), 314–324. https://doi.org/10.1002/hbe2.195

Al-Rashid, M. A., Nadeem, M., Campisi, T., Shamsul Harumain, Y. A., & Goh, H. C. (2022). How do psychosocial barriers shape public transport use? A mixed-method study among older adults in Pakistan. *Sustainability*, *14*(19), 12471. https://doi.org/10.3390/su141912471

Bai, X., Hung, K., & Lai, D. W. L. (2017). The role of travel in enhancing life satisfaction among Chinese older adults in Hong Kong. *Ageing and Society*, *37*(9), 1824–1848. https://doi.org/10.1017/S0144686X16000611

Ben-Akiva, M. E., & Lerman, S. R. (1985). *Discrete choice analysis: theory and application to travel demand* (Vol. 9). MIT press.

Böcker, L., van Amen, P., & Helbich, M. (2017). Elderly travel frequencies and transport mode choices in Greater Rotterdam, the Netherlands. *Transportation*, *44*(4), 831–852. https://doi.org/10.1007/s11116-016-9680-z

Boisjoly, G., & El-Geneidy, A. (2016). Daily fluctuations in transit and job availability: A comparative assessment of time-sensitive accessibility measures. *Journal of Transport Geography*, 52, 73-81.

Buehler, R., & Hamre, A. (2015). The multimodal majority? Driving, walking, cycling, and public transportation use among American adults. *Transportation*, *42*(6), 1081–1101. https://doi.org/10.1007/s11116-014-9556-z

Chen, J., Cheng, L., Chen, X., Chen, J., & Cao, M. (2021). Measuring accessibility to healthcare services for older bus passengers: A finer spatial resolution. *Journal of Transport Geography*, 93, 103068.

Chen, X., & Jia, P. (2019). A comparative analysis of accessibility measures by the two-step floating catchment area (2SFCA) method. *International Journal of Geographical Information Science, 33*(9), 1739-1758.

Chen, Y., Bouferguene, A., Shirgaokar, M., & Al-Hussein, M. (2020). Spatial analysis framework for age-restricted communities integrating spatial distribution and accessibility evaluation. *Journal of Urban Planning and Development, 146*(1), 04019021.

Chen, Y., Liu, B., Shen, Y., & Li, L. (2022). Assessing accessibility to service facilities for older people in age-restricted communities from the perspective of equity. *Journal of Transport & Health*, 27, 101515.

Cheng, G., Zeng, X., Duan, L., Lu, X., Sun, H., Jiang, T., & Li, Y. (2016). Spatial difference analysis for accessibility to high level hospitals based on travel time in Shenzhen, China. *Habitat International*, 53, 485-494.

Chihuri, S., Mielenz, T. J., DiMaggio, C. J., Betz, M. E., DiGuiseppi, C., Jones, V. C., & Li, G. (2016). Driving cessation and health outcomes in older adults. *Journal of the American Geriatrics Society*, *64*(2), 332–341. https://doi.org/10.1111/jgs.13931

Chudyk, A. M., Winters, M., Moniruzzaman, M., Ashe, M. C., Gould, J. S., & McKay, H. (2015). Destinations matter: The association between where older adults live and their travel behavior. *Journal of Transport and Health*, *2*(1), 50–57. https://doi.org/10.1016/j.jth.2014.09.008

Clarke, P., & Gallagher, N. A. (2013). Optimizing mobility in later life: The role of the urban built environment for older adults aging in place. *Journal of Urban Health*, *90*(6), 997–1009. https://doi.org/10.1007/s11524-013-9800-4

Coughlin, J. (2001). *Transportation and older persons: Perceptions and preferences*.

Dahan-Oliel, N., Mazer, B., Gélinas, I., Dobbs, B., & Lefebvre, H. (2010). Transportation use in community-dwelling older adults: Association with participation and leisure activities. *Canadian Journal on Aging, 29*(4), 491-502.

Dai, D., & Wang, F. (2011). Geographic disparities in accessibility to food stores in southwest Mississippi. *Environment and Planning B: Planning and Design, 38*(4), 659-677.

Dai, D. (2010). Black residential segregation, disparities in spatial access to healthcare facilities, and late-stage breast cancer diagnosis in metropolitan Detroit. *Health & Place, 16*(5), 1038-1052.

De Vos, J. (2022). The shifting role of attitudes in travel behaviour research. *Transport Reviews*, *42*(5), 573–579. https://doi.org/10.1080/01441647.2022.2078537

Delbosc, A., Currie, G. (2018). Accessibility and exclusion related to well being. Quality of life and daily travel. Springer, Berlin.

Diana, M., & Mokhtarian, P. L. (2009). Desire to change one's multimodality and its relationship to the use of different transport means. *Transportation Research Part F: Traffic Psychology and Behaviour*, *12*(2), 107–119. https://doi.org/10.1016/j.trf.2008.09.001

Dickerson, A. E., Molnar, L. J., Bédard, M., Eby, D. W., Berg-Weger, M., Choi, M., Grigg, J., Horowitz, A., Meuser, T., Myers, A., O'Connor, M., & Silverstein, N. M. (2019).

Transportation and aging: An updated research agenda to advance safe mobility among older adults transitioning from driving to non-driving. *The Gerontologist*, *59*(2), 215–221. https://doi.org/10.1093/geront/gnx120

Engels, B., & Liu, G. J. (2011). Social exclusion, location and transport disadvantage amongst non-driving seniors in a Melbourne municipality, Australia. *Journal of Transport Geography, 19*(4), 984-996.

Ettema, D., Gärling, T., Eriksson, L., Friman, M., Olsson, L. E., & Fujii, S. (2011). Satisfaction with travel and subjective well-being: Development and test of a measurement tool. *Transportation Research Part F: Traffic Psychology and Behaviour*, *14*(3), 167–175. https://doi.org/10.1016/j.trf.2010.11.002

Foley, D. J., Heimovitz, H. K., Guralnik, J. M., & Brock, D. B. (2002). Driving life expectancy of persons aged 70 years and older in the United States. *American Journal of Public Health*, *92*(8), 1284–1289. https://doi.org/10.2105/AJPH.92.8.1284

Fransen, K., Neutens, T., De Maeyer, P., & Deruyter, G. (2015). A commuter-based two-step floating catchment area method for measuring spatial accessibility of daycare centers. *Health & place*, 32, 65-73.

Freedman, V. A., Carr, D., Cornman, J. C., & Lucas, R. E. (2017). Aging, mobility impairments and subjective well-being. *Disability and Health Journal*, *10*(4), 525–531. https://doi.org/10.1016/j.dhjo.2017.03.011

Gaglione, F., Cottrill, C., & Gargiulo, C. (2021). Urban services, pedestrian networks and behaviors to measure elderly accessibility. *Transportation Research Part D: Transport and Environment*, 90, 102687.

Goodwin, P. B. (1974). Generalised time and the problem of equity in transport studies. *Transportation, 3*, 1–23. https://doi.org/10.1007/BF02351839

Graham, H., de Bell, S., Flemming, K., Sowden, A., White, P., & Wright, K. (2020). Older people's experiences of everyday travel in the urban environment: a thematic synthesis of qualitative studies in the United Kingdom. *Ageing and Society*, *40*(4), 842–868. https://doi.org/10.1017/S0144686X18001381

Guo, S., Song, C., Pei, T., Liu, Y., Ma, T., Du, Y., … & Wang, Y. (2019). Accessibility to urban parks for elderly residents: Perspectives from mobile phone data. *Landscape and urban planning, 191*, 103642.

Handy, S. L., & Niemeier, D. A. (1997). Measuring accessibility: An exploration of issues and alternatives. *Environment and Planning A*, 29(7), 1175-1194.

Hansen, W. (1959). How accessibility shape land use. *Journal of the American Institute of Planners*, 25(2), 73-76.

Hanson, S. (2010). Gender and mobility: new approaches for informing sustainability. *Gender, Place & Culture*, *17*(1), 5–23. https://doi.org/10.1080/09663690903498225

Heinen, E., & Mattioli, G. (2019). Does a high level of multimodality mean less car use? An exploration of multimodality trends in England. *Transportation*, *46*(4), 1093–1126. https://doi.org/10.1007/s11116-017-9810-2

Herzog, A. R., Ofstedal, M. B., & Wheeler, L. M. (2002). Social engagement and its relationship to health. *Clinics in geriatric medicine, 18*(3), 593-609.

Hong, Z., & Yan, J. (2015). Mapping accessibility and shortage of the protestant church in China: Applying two spatial research methods. *Asian Journal of Social Sciences and Management Studies, 2*(1), 1-16.

Hou, Y., Garikapati, V., Nag, A., Young, S. E., & Grushka, T. (2019). Novel and practical method to quantify the quality of mobility: Mobility energy productivity metric. *Transportation Research Record, 2673*(10), 141-152.

Hough, J. A., Cao, X., & Handy, S. L. (2008). Exploring travel behavior of elderly women in rural and small urban North Dakota. *Transportation Research Record: Journal of the Transportation Research Board*, *2082*(1), 125–131. https://doi.org/10.3141/2082-15

Jamal, S., & Newbold, K. B. (2020). Factors associated with travel behavior of millennials and older adults: A scoping review. *Sustainability*, *12*(19), 8236. https://doi.org/10.3390/su12198236

Jamtsho, S., Corner, R., & Dewan, A. (2015). Spatio-temporal analysis of spatial accessibility to primary healthcare in Bhutan. *ISPRS International Journal of Geo-Information, 4*(3), 1584-1604.

Kahneman, D., & Deaton, A. (2010). High income improves evaluation of life but not emotional well-being. Proceedings of the national academy of sciences, 107(38), 16489-16493.

Kim, S., & Ulfarsson, G. F. (2004). Travel mode choice of the elderly: Effects of personal, household, neighborhood, and trip characteristics. *Transportation Research Record: Journal of the Transportation Research Board*, *1894*(1), 117–126. https://doi.org/10.3141/1894-13

Kitamura, R., Mokhtarian, P. L., & Daidet, L. (1997). A micro-analysis of land use and travel in five neighborhoods in the San Francisco Bay Area. *Transportation*, *24*(2), 125–158. https://doi.org/10.1023/A:1017959825565

Kuhnimhof, T., Buehler, R., Wirtz, M., & Kalinowska, D. (2012). Travel trends among young adults in Germany: increasing multimodality and declining car use for men. *Journal of Transport Geography*, *24*, 443–450. https://doi.org/10.1016/j.jtrangeo.2012.04.018

Kuhnimhof, T., Chlond, B., & Von Der Ruhren, S. (2006). Users of transport modes and multimodal travel behavior. *Transportation Research Record: Journal of the Transportation Research Board*, *1985*(1), 40–48. https://doi.org/10.1177/0361198106198500105

Lättman, K., Olsson, L., Friman, M., & Fujii, S. (2019). Perceived accessibility, satisfaction with daily travel, and life satisfaction among the elderly. *International Journal of Environmental Research and Public Health*, *16*(22), 4498. https://doi.org/10.3390/ijerph16224498

Lawton, M. P., & Nahemow, L. (1973). Ecology and the aging process. In *The psychology of adult development and aging.* (pp. 619–674). American Psychological Association. https://doi.org/10.1037/10044-020

Lee, S., & Choi, H. (2020). Impact of older adults' mobility and social participation on life satisfaction in South Korea. Asian Social Work and Policy Review, 14(1), 4-10.

Levinson, D. M. (1998). Accessibility and the journey to work. *Journal of Transport Geography*, 6(1), 11-21.

Li, Z., Fan, Z., Song, Y., & Chai, Y. (2021). Assessing equity in park accessibility using a travel behavior-based G2SFCA method in Nanjing, China. *Journal of Transport Geography, 96*, 103179.

Liu, T., Huang, D., & He, Q. (2019). The relationship between street connectivity and accessibility: Evidence from multimodal transport networks in a suburban district of Beijing. *Journal of Transport Geography*, 77, 119-132.

Luiu, C., Tight, M., & Burrow, M. (2017). The unmet travel needs of the older population: a review of the literature. *Transport Reviews*, *37*(4), 488–506. https://doi.org/10.1080/01441647.2016.1252447

Luo, W., & Wang, F. (2003). Measures of spatial accessibility to healthcare in a GIS environment: synthesis and a case study in the Chicago region. *Environment and Planning B: Planning and Design, 30*(6), 865-884.

Luo, W., & Whippo, T. (2012). Variable catchment sizes for the two-step floating catchment area (2SFCA) method. *Health & Place, 18*(4), 789-795.

Luo, W., & Qi, Y. (2009). An enhanced two-step floating catchment area (E2SFCA) method for measuring spatial accessibility to primary care physicians. *Health & Place, 15*(4), 1100-1107.

Ma, L., & Cao, J. (2019). How perceptions mediate the effects of the built environment on travel behavior? *Transportation*, *46*(1), 175–197. https://doi.org/10.1007/s11116-017-9800-4

Metz, D. H. (2000). Mobility of older people and their quality of life. *Transport Policy*, *7*(2), 149–152. https://doi.org/10.1016/S0967-070X(00)00004-4

Neuburger, H. (1971). User benefits in the evaluation of transport and land use plans. *Journal of Transportation Economics and Policy*, 5, 52-75.

Miller, H.J. (2005), "Place-Based Versus People-Based Accessibility", Levinson, D.M. and Krizek, K.J. (Ed.) *Access to Destinations*, Emerald Group Publishing Limited, Leeds, pp. 63-89.

Molin, E., Mokhtarian, P., & Kroesen, M. (2016). Multimodal travel groups and attitudes: A latent class cluster analysis of Dutch travelers. *Transportation Research Part A: Policy and Practice*, *83*, 14–29. https://doi.org/10.1016/j.tra.2015.11.001

Mollenkopf, H., Marcellini, F., Ruoppila, I., Flaschenträger, P., Gagliardi, C., & Spazzafumo, L. (1997). Outdoor mobility and social relationships of elderly people. *Archives of Gerontology and Geriatrics*, *24*(3), 295–310. https://doi.org/10.1016/S0167-4943(97)00781-4

Moniruzzaman, Md., Páez, A., Nurul Habib, K. M., & Morency, C. (2013). Mode use and trip length of seniors in Montreal. *Journal of Transport Geography*, *30*, 89–99. https://doi.org/10.1016/j.jtrangeo.2013.03.007

Musselwhite, C. (2018). Introduction: Conceptualising travel, transport and mobility for older people. In C. Musselwhite (Ed.), *Transport, Travel and Later Life* (pp. 1–14). Emerald Publishing Limited. https://doi.org/10.1108/S2044-994120170000010002

Ni, J., Wang, J., Rui, Y., Qian, T., & Wang, J. (2015). An enhanced variable two-step floating catchment area method for measuring spatial accessibility to residential care facilities in Nanjing. *International Journal of Environmental Research and Public Health, 12*(11), 14490-14504.

Nobis, C. (2007). Multimodality. *Transportation Research Record: Journal of the Transportation Research Board*, *2010*(1), 35–44. https://doi.org/10.3141/2010-05

Nordbakke, S., & Schwanen, T. (2014). Well-being and mobility: A theoretical framework and literature review focusing on older people. *Mobilities*, *9*(1), 104–129. https://doi.org/10.1080/17450101.2013.784542

Nordbakke, S., & Schwanen, T. (2015). Transport, unmet activity needs and well-being in later life: exploring the links. *Transportation*, *42*(6), 1129–1151. https://doi.org/10.1007/s11116-014-9558-x

Odoki, J. B., Kerali, H. R., & Santorini, F. (2001). An integrated model for quantifying accessibility-benefits in developing countries. *Transportation Research Part A: Policy and Practice, 35*(7), 601-623.

Ozbilen, B., Akar, G., White, K., Dabelko-Schoeny, H., & Cao, Q. (2022). Analysing the travel behaviour of older adults: what are the determinants of sustainable mobility? *Ageing and Society*, 1–29. https://doi.org/10.1017/S0144686X22001180

Páez, A., Anjum, Z., Dickson-Anderson, S. E., Schuster-Wallace, C. J., Ramos, B. M., & Higgins, C. D. (2020). Comparing distance, time, and metabolic energy cost functions for walking accessibility in infrastructure-poor regions. *Journal of Transport Geography*, 82, 102564.

Qin, J., Luo, S., Yi, D., Jiang, H., & Zhang, J. (2022). Measuring cluster-based spatial access to shopping stores under real-time travel time. *Sustainability, 14*(4), 2310.

Radke, J., & Mu, L. (2000). Spatial decompositions, modeling and mapping service regions to predict access to social programs. *Geographic Information Sciences, 6*(2), 105-112.

Ralph, K. M. (2017). Multimodal millennials? The four traveler types of young people in the United States in 2009. *Journal of Planning Education and Research*, *37*(2), 150–163. https://doi.org/10.1177/0739456X16651930

Ravensbergen, L., Van Liefferinge, M., Isabella, J., Merrina, Z., & El-Geneidy, A. (2022). Accessibility by public transport for older adults: A systematic review. *Journal of Transport Geography, 103*, 103408.

Ravensbergen, L., Varickanickal, J., Newbold, K. B., & Mohamed, M. (2023). A mixed-methods investigation of older adults' public transit use and travel satisfaction. *Travel Behaviour and Society*, *32*, 100577. https://doi.org/10.1016/j.tbs.2023.100577

Rosenbloom, S. (2009). Meeting transportation needs in an aging-friendly community. *Generations*, *33*(2), 33–43.

Sallis, J. F., Cervero, R. B., Ascher, W., Henderson, K. A., Kraft, M. K., & Kerr, J. (2006). An ecological approach to creating active living communities. *Annual Review of Public Health*, *27*(1), 297–322. https://doi.org/10.1146/annurev.publhealth.27.021405.102100

Satariano, W. A., Guralnik, J. M., Jackson, R. J., Marottoli, R. A., Phelan, E. A., & Prohaska, T. R. (2012). Mobility and aging: New directions for public health action. *American Journal of Public Health*, *102*(8), 1508–1515. https://doi.org/10.2105/AJPH.2011.300631

Schwanen, T., Dijst, M., & Kwan, M. (2008). ICTs and the decoupling of everyday activities, space and time: Introduction. *Tijdschrift Voor Economische En Sociale Geografie*, *99*(5), 519–527. https://doi.org/10.1111/j.1467-9663.2008.00489.x

Schwanen, T., & Páez, A. (2010). The mobility of older people – an introduction. *Journal of Transport Geography*, *18*(5), 591–595. https://doi.org/10.1016/j.jtrangeo.2010.06.001

Schwanen, T., & Ziegler, F. (2011). Well-being, independence and mobility: An introduction. *Ageing and Society*, *31*(5), 719–733. https://doi.org/10.1017/S0144686X10001467

Shergold, I., Lyons, G., & Hubers, C. (2015). Future mobility in an ageing society – Where are we heading? *Journal of Transport & Health*, *2*(1), 86–94. https://doi.org/10.1016/j.jth.2014.10.005

Shye, D., Mullooly, J. P., Freeborn, D. K., & Pope, C. R. (1995). Gender differences in the relationship between social network support and mortality: A longitudinal study of an elderly cohort. *Social Science & Medicine*, *41*(7), 935–947. https://doi.org/10.1016/0277-9536(94)00404-H

Smith, G. C., & Sylvestre, G. M. (2001). Determinants of the travel behavior of the suburban elderly. *Growth and Change*, *32*(3), 395–412. https://doi.org/10.1111/0017-4815.00165

Spears, S., Houston, D., & Boarnet, M. G. (2013). Illuminating the unseen in transit use: A framework for examining the effect of attitudes and perceptions on travel behavior. *Transportation Research Part A: Policy and Practice*, *58*, 40–53. https://doi.org/10.1016/j.tra.2013.10.011

Taniguchi, A., Grääs, C., & Friman, M. (2014). Satisfaction with travel, goal achievement, and voluntary behavioral change. *Transportation Research Part F: Traffic Psychology and Behaviour*, *26*, 10–17. https://doi.org/10.1016/j.trf.2014.06.004

Tao, Z., Cheng, Y., Dai, T., & Rosenberg, M. W. (2014). Spatial optimization of residential care facility locations in Beijing, China: Maximum equity in accessibility. *International Journal of Health Geographics, 13*(1), 1-11.

Tao, Z., Yao, Z., Kong, H., Duan, F., & Li, G. (2018). Spatial accessibility to healthcare services in Shenzhen, China: Improving the multimodal two-step floating catchment area method by estimating travel time via online map APIs. *BMC Health Services Research, 18*(1), 1-10.

Tolmie, A., & Thomson, J. (2003). Attitudes, social norms and perceived behavioural control in adolescent pedestrian decision-making. *Behavioural Research in Road Safety: Thirteenth Seminar Proceedings*, 55–64.

VERBI Software. (2021). MAXQDA 2022 [computer software]. Berlin, Germany: VERBI Software. Available from maxqda.com.

Vickerman, R. W. (1974). Accessibility, attraction and potential: A review of some concepts and their use in determining mobility. *Environment and Planning A*, 6, 675-691.

Vivoda, J. M., Harmon, A. C., Babulal, G. M., & Zikmund-Fisher, B. J. (2018). E-hail (rideshare) knowledge, use, reliance, and future expectations among older adults.

Transportation Research Part F: Traffic Psychology and Behaviour, *55*, 426–434. https://doi.org/10.1016/j.trf.2018.03.020

Wachs, M., & Kumagai, T. (1973). Physical accessibility as a social indicator. *Socioeconomic Planning Science*, 7, 327-456.

Wan, N., Zou, B., & Sternberg, T. (2012). A three-step floating catchment area method for analyzing spatial access to health services. *International Journal of Geographical Information Science, 26*(6), 1073-1089.

Wan, N., Zhan, F. B., Zou, B., & Chow, E. (2012). A relative spatial access assessment approach for analyzing potential spatial access to colorectal cancer services in Texas. *Applied Geography, 32*(2), 291-299.

Wang, F., & Tang, Q. (2013). Planning toward equal accessibility to services: A quadratic programming approach. *Environment and Planning B: Planning and Design, 40*(2), 195-212.

Wang, F., & Xu, Y. (2011). Estimating O-D travel time matrix by Google Maps API: Implementation, advantages, and implications. *Annals of GIS, 17*(4), 199-209.

Wasfi, R., Levinson, D., & El-Geneidy, A. (2012). Measuring the transportation needs of seniors. *Journal of Transport Literature, 6*, 8-32.

Wei, Y. (2013). How long and how far do adults travel and will adults travel for primary care? Washington State Office of Financial Management.

World Health Organization. (2020). Coronavirus disease 2019 (COVID-19): Situation report, 73.

Wu, B. (2020). Social isolation and loneliness among older adults in the context of COVID-19: A global challenge. *Global Health Research and Policy, 5*(1), 27.

Yao, J., Murray, A. T., & Agadjanian, V. (2013). A geographical perspective on access to sexual and reproductive healthcare for women in rural Africa. *Social Science & Medicine, 96*, 60-68.

Yen, I. H., Shim, J. K., Martinez, A. D., & Barker, J. C. (2012). Older people and social connectedness: How place and activities keep people engaged. *Journal of Aging Research*, *2012*, 1–10. https://doi.org/10.1155/2012/139523