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TRAVEL BEHAVIOR AND DEMAND

Final Project Report

Promoting Sustainable Travel within Communities through Behavioral Interventions and Emerging Mobility Solutions

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16. Abstract This project investigates behavioral interventions and emerging mobility solutions to promote sustainable travel behavior. It focuses on a portfolio of behavioral interventions organized into two main strategies: (i) health- and environment-focused messaging to highlight the benefits of walking, biking, and transit, and (ii) gamification techniques such as badges and leaderboards to motivate behavior change through social engagement and goal achievement. These interventions were evaluated through two large-scale stated-preference surveys of over 8,949 U.S. travelers in total. Results showed that gain-framed messages emphasizing health and air quality improvements increased the appeal of sustainable modes, while gamified feedback mechanisms significantly enhanced motivation and engagement. In parallel, to enhance access to sustainable modes such as micromobility and ridesourcing, essential complements to behavioral interventions, the project initiated the development of optimization models to guide the strategic deployment of emerging mobility services. These models, which will be further advanced in Stage 2, provide the infrastructure planning needed to integrate behavioral and service-based strategies. The study concludes that combining behavioral interventions with improved access to sustainable mobility services offers a promising approach for advancing transportation sustainability. These findings can inform the development of incentive programs, mobile apps for promoting mode shift, and public education campaigns aimed at increasing the adoption of active and shared transportation modes.			
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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

Transportation systems directly affect public health, environmental outcomes, and access to many essential destinations (e.g., jobs, education, grocery stores, and healthcare). However, conventional transit networks often fall short in providing adequate coverage and flexibility, particularly in areas underserved by fixed-route services. In such contexts, personal vehicle dependency remains high, contributing to increased emissions, lower physical activity, and limited adoption of sustainable travel modes.

This project, funded under the Georgia Tech TBD Center, investigates low-cost, scalable strategies to promote more sustainable travel behavior. Although originally submitted as a standalone effort, it is now referred to as *Stage 1*, following the subsequent funding and launch of *Stage 2*, which extends this work. Stage 1 focused on two complementary thrusts: (1) the design and evaluation of behavioral interventions to shift travelers from personal vehicles to sustainable modes such as walking, biking, and transit; and (2) the development of optimization models to guide the strategic deployment of emerging mobility options (e.g., micromobility and resourcing) through public-private partnerships. While the behavioral interventions directly target mode shift, the modeling work supports those interventions by improving availability of viable sustainable alternatives (e.g., micromobility, ridesourcing, and coordinated multimodal transit systems), thereby enhancing access to essential destinations.

The behavioral component included two stated-preference experiments with 8,949 U.S. travelers. One tested health- and environment-focused messages; the other evaluated gamification strategies including badges and leaderboards. Results demonstrated that gain-framed messaging increased traveler interest in sustainable modes, and that gamification elements promoting social comparison enhanced engagement and motivation. To complement these efforts, a set of preliminary optimization models was developed to identify where emerging mobility services should be deployed to address gaps in access and enable multimodal travel. These models incorporated system performance objectives, and were tested on small, synthetic networks to confirm feasibility. Further model refinement, calibration using real-world data, and simulation of policy impacts will be carried out in Stage 2, using the City of Peachtree Corners, GA, as the testbed.

The novelty of this project lies in its integration of behavioral intervention design with the strategic planning of access-enabling mobility services. Unlike previous work that treats behavioral change and transportation infrastructure separately, this study develops a unified framework that links user motivation, service availability, and deployment strategy.

Key outputs of Stage 1 include survey datasets, experimental findings, incentive designs, and preliminary models for evaluating emerging mobility deployments. Outcomes include improved understanding of behavior change mechanisms and data-driven insights to inform personalized messaging and service coordination strategies. The impacts of Stage 1 include demonstrated potential for low-cost interventions (such as health-focused messaging and gamified feedback) to influence sustainable travel behavior, preliminary optimization models to guide strategic deployment of emerging mobility services, and expanded multidisciplinary knowledge at the intersection of transportation engineering, behavioral science, public policy, data analytics, and operations research.

1. Introduction

Communities today face multifaceted transportation challenges, including limited mobility options, dependency on personal vehicles, rising emissions, and associated health impacts. These challenges hinder efforts to achieve sustainable transportation objectives such as improved mobility, environmental sustainability, public health, and fairness in access to societal services and essential destinations (e.g., jobs, education, healthcare, and grocery stores). Addressing these issues requires comprehensive strategies that not only motivate sustainable travel behaviors but also provide access to alternative sustainable travel modes, such as transit and biking.

To systematically address these complex transportation challenges, the "Promoting Sustainable Travel within Communities through Behavioral Interventions and Emerging Mobility Solutions" project was initiated, funded by the Understanding the Future of Travel Behavior and Demand (TBD) center at the Georgia Institute of Technology. The project aims to integrate behavioral interventions with strategic deployment of emerging mobility solutions through public-private partnerships, thereby enhancing the overall sustainability of transportation systems. Although originally submitted as a standalone effort, it is now referred to as *Stage 1*, following the subsequent funding and launch of *Stage 2* project, which extends this work.

Stage 1, detailed in this report, focuses on developing foundational methods to encourage sustainable travel behavior and expand access to viable sustainable alternatives to personal vehicle use. The primary emphasis is on designing and evaluating behavioral interventions aimed at shifting travelers toward more sustainable modes such as transit, walking, and biking. These interventions include health- and environment-oriented informational messaging and gamification strategies using badges and leaderboards. A series of online stated-preference surveys involving over 8,949 U.S. travelers provides the empirical basis for evaluating these strategies and yields insights into user preferences and behavioral responses.

In parallel, the project initiates the development of optimization models to identify where emerging mobility services, such as micromobility and ridesourcing, can be deployed to address access gaps in existing transit systems. These models are designed to improve mobility in areas underserved by fixed-route services and support future coordination between public agencies and private operators. While preliminary experiments on small grid networks confirm the feasibility of the approach, detailed evaluation, calibration with real-world data, and network-scale implementation are planned for Stage 2, using the City of Peachtree Corners, Georgia, as the study area.

The rest of the report is organized as follows. Chapter 2 details the design and evaluation of behavioral interventions using health and environmental messaging, assessed through a series of online stated-preference surveys. Chapter 3 examines additional behavioral intervention strategies, specifically focusing on gamification techniques and their impacts on promoting sustainable travel choices. Chapter 4 shifts attention to optimization-based modeling approaches developed to support the strategic deployment of emerging mobility services and to facilitate public-private partnerships, including preliminary numerical experiments on small-sized networks. Chapter 5 summarizes the main outputs, outcomes, and impacts achieved through Stage 1 efforts, highlighting contributions to behavioral insights, mobility planning, and workforce development. Chapter 6 concludes the report by synthesizing major findings, discussing their broader significance, and outlining the transition to implementation and validation in Stage 2.

2. Effectiveness of Health and Environmental Information to Promote Sustainable Travel Modes

2.1 Introduction

The transportation sector in the U.S. is the largest contributor of greenhouse gas emissions, especially personal vehicle usage, accounting for 28% of total emissions (US EPA, 2024). Travel-related air pollutants, such as NO_2 and PM2.5, are associated with respiratory illnesses in adults and children, heart diseases and strokes, and adverse birth outcomes such as premature and low-weight births (Boogaard et al., 2022; Krzyzanowski et al., 2005; Zhang & Batterman, 2013). These negative environmental and health externalities of personal vehicle usage impact individuals as well as their community, amounting to $260 billion in yearly social costs, including healthcare expenses and environmental damage (Choma et al., 2021). Community-wide adoption of sustainable travel modes such as transit, walking, and biking can offset these social costs by alleviating congestion and emissions, promoting active mobility, and improving air quality and public health. While some urban areas may have lower personal vehicle usage due to factors such as high parking costs, safety concerns, or congestion, census data (U.S. Census Bureau, 2021) reveals a substantial reliance on personal vehicles among travelers. For instance, 82.27% of U.S. population depends on personal vehicles, while 53.71% in the New York metropolitan area and 80.43% in Metro Atlanta rely on personal vehicles. These figures underscore the significant dependance on personal vehicles. Despite the positive health and environmental impacts of sustainable modes, promoting them is challenging due to the high reliance on personal vehicles. Moreover, real-time trip-specific information about the immediate health and environmental benefits is seldom available to travelers at the time of decision-making, indicating a critical gap in information availability.

Information provision has been shown to be effective in inducing sustainable behavior in many decision contexts, including selection of healthy foods (Folkvord et al., 2020), energy conservation (Asensio & Delmas, 2015; Bonan et al., 2020), recycling and reuse (Goldstein et al., 2008), and waste reduction (Goldstein & Cialdini, 2011). For example, pro-social information provision about community benefits has been found to be effective in reducing energy consumption (Antinyan & Asatryan, 2019; Asensio & Delmas, 2015; Hagman et al., 2015; Hands, 2020, 2021; Nagatsu, 2015; Vainre et al., 2020) and pro-self-information provision about health warnings on cigarette packages has been found to be effective in promoting public health (Beshears et al., 2009; Hagman et al., 2015; Hammond et al., 2006). In the context of travel mode choice, preliminary studies have found that information provision related to the benefits of sustainable modes has high potential in demoting personal vehicle usage (Geng et al., 2020; M. Keall et al., 2015; Sulikova & Brand, 2022). However, these studies primarily relied on educating the participant about the health and environmental benefits of sustainable modes, rather than examining the impact of real-time trip-specific information provision. In promoting sustainable modes, the potential of real-time information provision about the associated health and environmental benefits is yet to be studied. Hence, this study examines the effectiveness of different health and environmental information in promoting sustainable modes.

Promising studies from public health literature show that benefits such as calories burned (R. Sallis et al., 2015; Xu, 2019), step counts (Smith-McLallen et al., 2017), and heart health improvement (Lee & Buchner, 2008; Ogilvie et al., 2007) are effective in promoting physical activity. However, they did not examine these benefits in the travel context. Air quality and carbon emissions have been investigated as effective environmental information in promoting sustainable modes (Ahmed et al., 2018; Chapman et al., 2018; Geng et al., 2016; M. D. Keall et al., 2018), but real-time trip-specific information has not been examined for its impact on promoting these modes. This study examines the effectiveness of real-time information provision in promoting three sustainable modes: bus transit, walking, and biking. The information provision includes three types of health information (i.e., step counts, calories burned, and heart health) and two types of environmental information (air quality and emissions).

Traditionally, tolling and congestion pricing have been implemented to reduce private car usage (Albert & Mahalel, 2006a; Basso et al., 2021). However, public perception of these approaches is generally negative (Albert & Mahalel, 2006a; Y. Li et al., 2019; Selmoune et al., 2020), further exacerbated by the inequitable nature of their impacts on disadvantaged groups, such as low-income travelers (Jaensirisak et al., 2005; Weinstein & Sciara, 2006). To overcome the issue of inequity, monetary incentives (e.g., reward points and cash) have been explored in various travel contexts, such as shifting to alternative travel routes, changing travel modes, and redistributing travel demand to reduce peak-hour congestion (Avineri & Steven, 2013; Ettema et al., 2010; Farooqui et al., 2014; Guo et al., 2021; T. Li et al., 2021; Y. Li et al., 2019; Riggs, 2020; Wang et al., 2021a). While these monetary incentives are equitable, they are not sustainable in the long run because forming and maintaining sustainable travel habits requires continuous provision of cash incentives over time which is often impractical due to limited funding (Farooqui et al., 2014; T. Li et al., 2021). By contrast, given the widespread use of mobile devices, health and environmental information provision can be implemented in real-time through mobile apps at a significantly lower cost.

This study employs a stated preference survey design to test the effectiveness of different informational messages in promoting sustainable modes. The findings from this study can provide insights on which messages have higher potential in promoting sustainable modes, enabling policymakers to take the necessary steps to implement them in the real world. Low-cost strategies for possible implementation of these messages in communities across the U.S. using mobile apps is discussed. The rest of the chapter is organized as follows: Section 2.2 illustrates the methods, Section 2.3 presents results, Section 2.4 discusses the results and offers insights, and Section 2.5 provides concluding remarks.

2.2 Methodology

This study uses a stated preference survey design and was approved by Georgia Tech's Institutional Review Board (#H23240). The survey is randomized and includes several treatment groups to test the effectiveness of different health and environment related informational messages in promoting sustainable travel modes: bus transit, walking, and biking. The informational messages under five different categories were carefully crafted to convey the associated health and environmental benefits to individual traveler (pro-self), or their community (pro-social), or both (pro-self + pro-social) to promote sustainable modes. Each message highlights a health or environmental benefit and targets a specific sustainable mode. A series of small-scale surveys were conducted to improve the framing (in terms of context, language, and tone) of the messages. The following categories of informational messages were tested:

- Environmental – emissions
- Environmental – air quality
- Active health – step count

- Active health – calories burned
- Heart health

2.2.1 *Informational messages using emissions*

This set of messages highlights trip-specific emission reductions of each target mode compared to personal vehicle travel. Messages in **Table 1** communicate different scales of benefits (pro-self: benefit to individual travelers, pro-social: benefit to community, i.e., neighborhood) corresponding to the improvement in air quality resulting from emission reductions.

Table 1: Informational messages using emissions

Scale of benefit	Target mode	Informational message
Pro-self	Bus	"Take the bus to reduce 0.7 pounds of carbon emissions and improve the air you breathe"
Pro-social	Bus	"Take the bus to reduce 0.7 pounds of carbon emissions to improve the air in your neighborhood"
Pro-self and pro-social	Bus	"Take the bus to reduce 0.7 pounds of carbon emissions to improve the air you and your neighbors breathe"
Pro-self	Walk	"Walk to reduce 1.2 pounds of carbon emissions to improve the air you breathe"
Pro-social	Walk	"Walk to reduce 1.2 pounds of carbon emissions to improve the air in your neighborhood."
Pro-self and pro-social	Walk	"Walk to reduce 1.2 pounds of carbon emissions to improve the air you and your neighbors breathe"
Pro-self	Bike	"Bike to reduce 1.2 pounds of carbon emissions to improve the air you breathe"
Pro-social	Bike	"Bike to reduce 1.2 pounds of carbon emissions to improve the air in your neighborhood"
Pro-self and pro-social	Bike	"Bike to reduce 1.2 pounds of carbon emissions to improve the air you and your neighbors breathe"

2.2.2 *Informational messages using air quality*

Taking bus transit can reduce the exposure to air pollutants as buses undergo stringent maintenance, including regular air filter replacements, compared to personal vehicles where air filter maintenance is often neglected. Informational messages in **Table 2** are designed to illustrate the benefits of taking bus transit on air quality and the resultant reduced exposure to air pollutants. Three different messages are selected to differentiate the benefits to individual traveler, the community (e.g., neighborhood), and both.

Table 2: Informational messages using air quality

Scale of benefit	Target mode	Informational message
Pro-self	Bus	"Limit your exposure to air pollutants"
Pro-social	Bus	"Take the bus to reduce your neighborhood's exposure to air pollutants"
Pro-self and pro-social	Bus	"Take the bus to limit your and your neighborhood's exposure to air pollutants"

2.2.3 Informational messages using active health

Walking 10,000 steps a day is a popular health campaign that points to several health benefits, including improved blood pressure (Wattanapisit & Thanamee, 2017). Informational messages using daily steps can illustrate the progress of a traveler's daily step counts by adopting walking as a travel mode. Similarly, fitness tracking apps, such as Fitbit or Apple Health, are widely used to track calories burned during the day. Messages illustrating the calories burned by choosing walking or biking can communicate the impact of travel on active health. While maintaining an active lifestyle is beneficial to an individual traveler, it also positively benefits community health (Lee & Buchner, 2008). **Table 3** shows eight messages designed to communicate the step counts and calories burned from walking and biking. While showcasing the calories burned, equivalent number of cookies are presented to make it more relatable.

Table 3: Informational messages using active health

Scale of benefit	Target mode	Informational message
	Step counts	
Pro-self	Walk	"Complete 30% of your suggested daily steps"
Pro-social	Walk	"Walk to improve community health"
Pro-self and pro-social	Walk	"Walk to improve community health while completing 30% of suggested daily steps"
	Calorie counts	
Pro-self	Walk	"You can burn up to 115 calories or 3 cookies"
Pro-self and pro-social	Walk	"Walk to improve community health while burning 115 calories or 3 cookies"
Pro-self	Bike	"You can burn up to 45 calories or 1 cookie"
Pro-social message	Bike	"Bike to improve community health"
Pro-self and pro-social	Bike	"Bike to improve your community health while burning 45 calories or 1 cookie"

2.2.4 Informational messages using heart health

Walking and biking are shown to reduce the risk of cardiovascular diseases (Ekblom-Bak et al., 2014). Individual heart health improvement collectively improves community health. Messages in **Table 4** are designed to convey these benefits to travelers.

Table 4: Informational messages using heart health

Scale of benefit	Target mode	Informational message
Pro-self	Walk	"Walk to improve your heart health"
Pro-self and pro-social	Walk	"Walk to improve your heart health and community health"
Pro-self	Bike	"Bike to improve your heart health"
Pro-self and pro-social	Bike	"Bike to improve your heart health and community health"

2.2.5 Survey design

A stated preference survey design is employed to test the various informational messages. The survey takes 5-7 minutes to complete and consists of three parts as illustrated in **Figure 1**: (1) sociodemographic questions, (2) travel preference questions, and (3) scenario-based stated preference questions. The sociodemographic questions include age, gender, race, ethnicity, employment, education, and income (detailed questions are presented in **Appendix A: Part 1 (Demographics**). Travel preference questions include participants' usual travel time to work, their preferred travel modes for commute and non-commute trips, and a 7-point Likert scale question, ranging from 1 (strongly disagree) to 7 (strongly agree), with various statements (as outlined in **Table 5**, along with the intent of each statement) to gather data on opinions about health, environment, and willingness to choose alternative sustainable modes. A copy of the travel preference portion of the survey is presented in **Appendix A: Part 2 (Travel Behavior Questions)**.

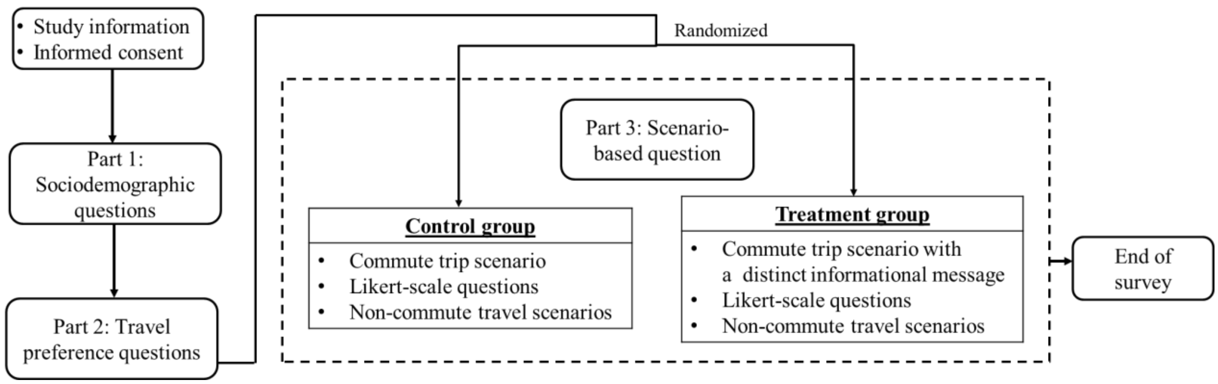
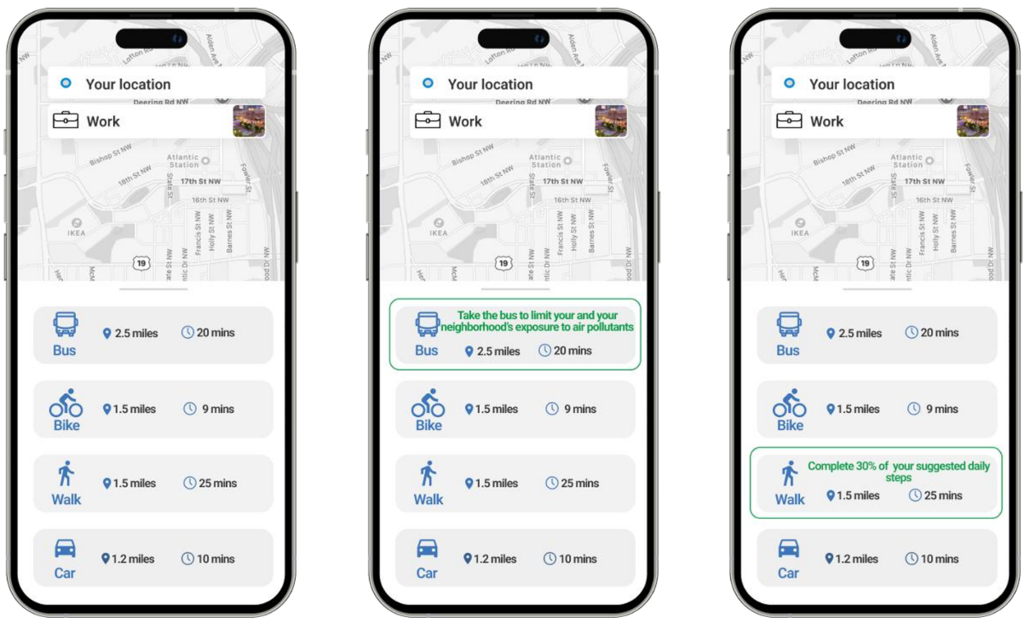


Figure 1: Survey flow

Table 5: Likert scale questions

Statement	Intent
I am open to trying out alternative modes (other than my preferred modes) for daily commute trips	Willingness to use alternative modes for commute trips
I am open to trying out alternative modes (other than my preferred modes) for daily non-commute trips	Willingness to use alternative modes for non-commute trips
I am concerned about my carbon footprint	Concern about carbon footprint
If I knew how to better reduce carbon footprint, I would take action	Willingness to take action to reduce carbon footprint
I maintain an active lifestyle	Level of physical activity
I am health conscious	Health consciousness
If I knew how to better contribute to improve air quality, I would take action	Willingness to take action to improve air quality

Scenario-based stated preference questions present participants with a hypothetical commute scenario, displaying a customized image of a mobile app featuring different travel options coupled with informational messages (a few examples are shown in **Figure 2**), mimicking a real-time travel decision-making. An example of the scenario-based questions when presented with health and environmental informational messages is presented in **Appendix A (An Example of Informational Messaging)**. The survey is conducted as randomized control trials where, in the control group the scenario questions offer travel options with travel information, while each treatment group is presented with the scenario questions containing both travel information with a distinct informational message. Travel information, such as travel time and distance corresponding to each mode, remains the same across all treatment and control groups. The scenario-based questions are phrased as "Suppose you are on your way to work, and you use a navigation app (such as Google Maps, Apple Maps, Waze, etc.). You have four alternative options as shown in the screen below. Assume all four options are available to you. Please choose the option you prefer the most.” As a follow-up to the scenario-based question, participants are asked to rate a few statements such as “I would change my behavior based on the message” on a 7-point Likert scale ranging from 1 (strongly disagree) to 7 (strongly agree). Additionally, after the scenario-based question, participants are asked whether they would consider using the target mode for six different types of non-commute trips (i.e., shopping, entertainment, social, fitness, medical, and errands).



A. Control **B. Treatment examples**

Figure 2: Examples of images used in the scenario-based questions

2.2.6 Participant recruitment and sampling

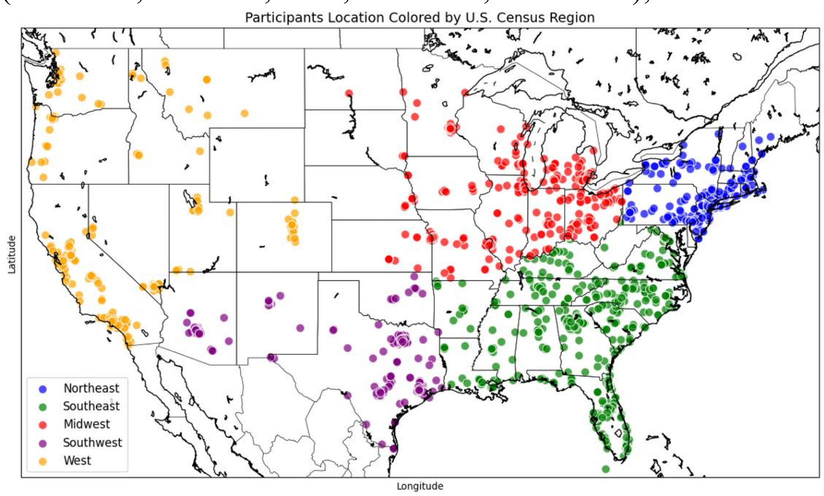
Participants were recruited via the Prolific survey data collection platform based on the criteria that they are 18 years or older, live in the U.S., and are primarily car users. The participants were compensated based on the standard rates set by Prolific. An informed consent was presented to the participants at the beginning of the survey as shown in **Figure 1**.

2.3 Results

A total of 4,480 participants completed the survey, balanced across gender, income, and census regions. The participants were randomly assigned to one of the 25 groups (24 treatment and 1 control groups). A one-way ANOVA conducted on the sociodemographic variables revealed that there were no significant differences among the groups, indicating that the randomization was successful, and the groups were comparable in terms of sociodemographic characteristics.
Overall, the participants rated positively across various Likert scale statements listed in **Table 5**. Specifically, 78.92% of the participants indicated that they are health conscious, and 71.85% indicated that they maintain an active lifestyle. Overall, 56.24% of participants expressed concern about their carbon footprint, and 60.43% indicated a willingness to take action to reduce it.

2.3.1 Descriptive statistics

The survey participants are geographically diverse and spread across the U.S. Census regions (Southeast, Midwest, West, Northeast, Southwest), as shown in **Figure 3**.



Region	% participants
Southeast	30.70
Midwest	22.72
West	18.63
Northeast	15.32
Southwest	12.64

Figure 3: Participant locations by U.S. census region

The participants are also evenly split by sex with 49.9% females and 49.4% males as shown in **Figure 4**.

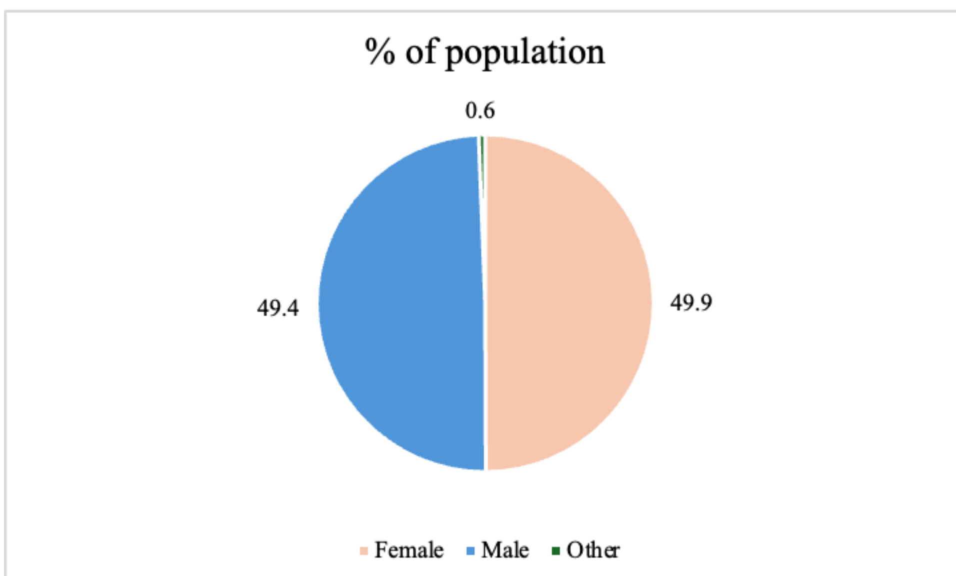


Figure 4: Percentage of female and male among the survey participants

The age distribution of the survey participants is skewed toward middle age, with over 70% between 30 and 59 years old, as shown in **Figure 5**. The largest share of participants is between 40 and 49 years old. Younger adults aged 29 and below accounted for 13.5% of the sample, whereas older adults aged 70 and above represented only 1.8%. The Prolific survey platform had relatively few participants aged 60 and above in its participant pool.

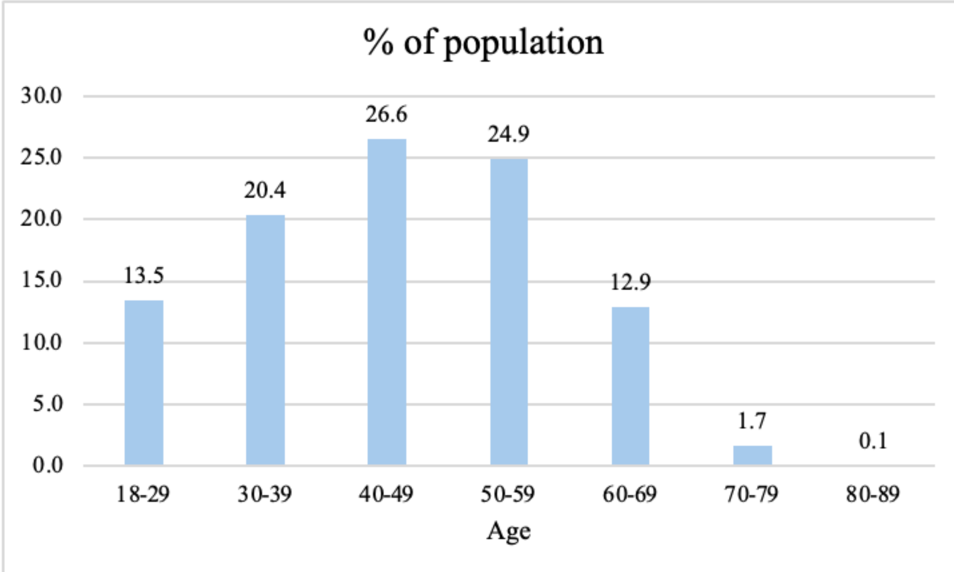


Figure 5: Percentage of participants by age in the survey sample

Figure 6 shows that the income distribution is slightly skewed, with 43.3% of participants reporting an annual household income of $80,000 or higher, and only 18.7% reporting income lower than $29,000.

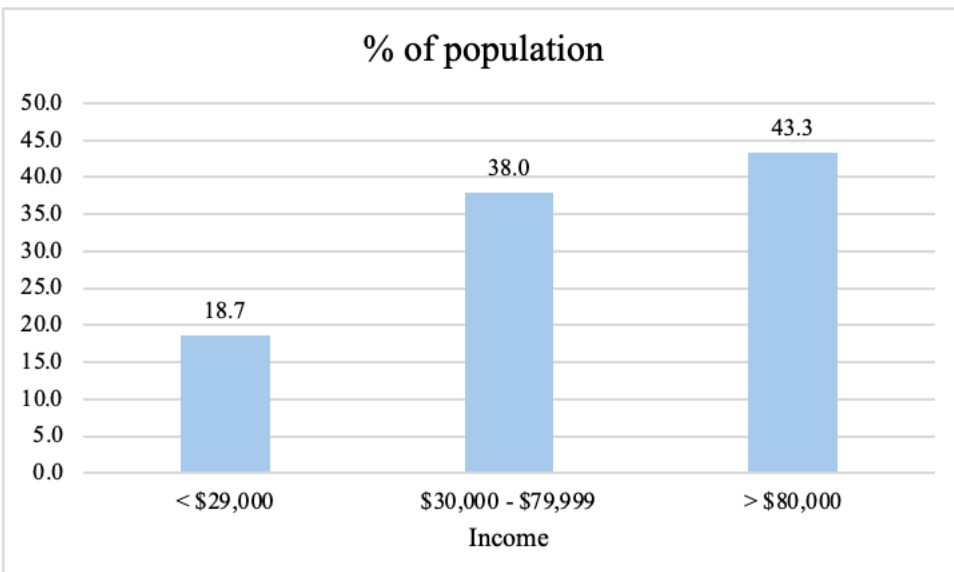


Figure 6: Percentage of participants by income level in the survey sample

The reported Likert-scale ratings to questions listed in Table 5 about participants' opinions on health, environment, and willingness to take action are presented as a stacked bar chart in Figure 7. These ratings revealed generally positive sentiments (somewhat agree, agree, or strongly agree) toward health and the environment. 77.57% of participants rated somewhat agree or higher on the health consciousness statement, and 70.22% rated somewhat agree or higher on the active lifestyle statement, indicating a strong personal health orientation. While 54.4% of participants indicated concern for their carbon footprint, more than 59% were willing to take action to reduce it.

Similarly, over 68% were willing to take action to improve their air quality. Overall, more than 56% of participants were willing to change their daily commute or non-commute modes.

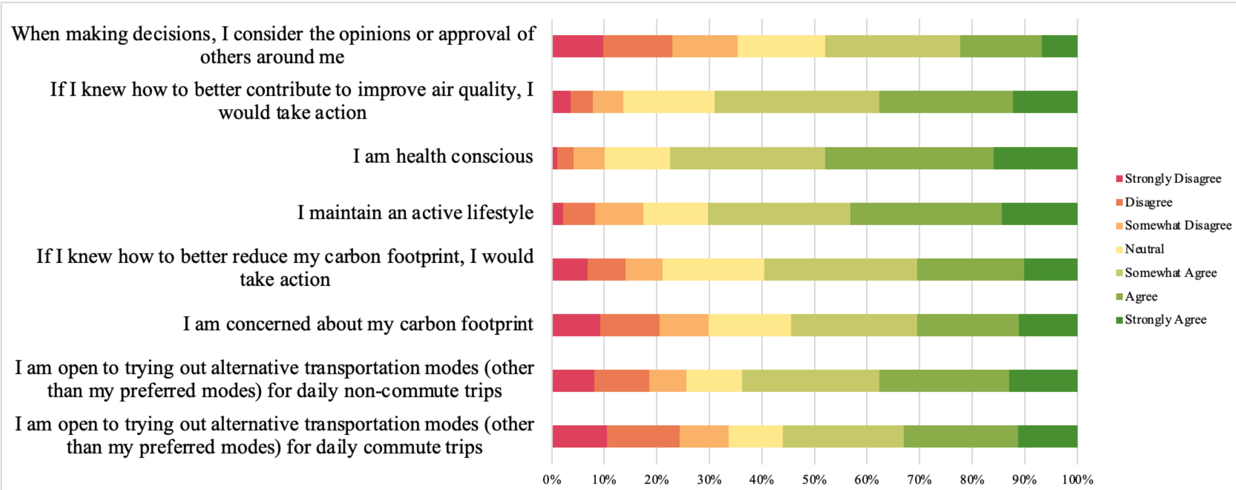


Figure 7: Participants' response to health and environmental opinions

2.3.2 Effects of informational messages on stated travel mode choice

Since the responses to the scenario questions are categorical dependent variables, to understand the effectiveness of the informational messages on the mode choice, a multinomial logistic regression is used (**Equation 1**). Each informational message's effect is compared against the control group, with the baseline choice being the car (against which other mode choices are evaluated).

$$U_n = \beta X_n + \epsilon_n \tag{1}$$

Here, U_n represents the utility of participant n, X_n denotes the explanatory variables, β represents the corresponding coefficients, and ϵ_n is the error term.

Illustrated in **Figure 8** are the odds ratios indicating the effectiveness of informational messages using emissions information on participants' likelihood to choose sustainable travel modes in the scenario question (i.e., bus, walk, and bike) compared to the control group. Pro-self messages that emphasize personal health benefits and improved air quality increased the odds of choosing the bus by over 3.6 times. Both pro-self and pro-self + pro-social messages also increased the odds of choosing the bus by over 2.5 times, with the effects of all three messages being statistically significant. This indicates that communicating emissions information can be an effective way to promote bus transit. In promoting walking, all informational messages using emissions information that appealed to personal health benefits, community health, or both were overall effective. However, communicating the air quality improvement in the neighborhood increased the likelihood of choosing to walk by almost 2.4 times.

In contrast, emissions-based informational messages targeting biking were overall less effective, with an average increase of only 1.6 times. The messages themselves might not be sufficient to encourage biking. The overall effectiveness of emissions-based messaging could be attributed to 54.40% of participants expressing concern about their carbon footprint and 59.51% indicating a willingness to take action to reduce it.

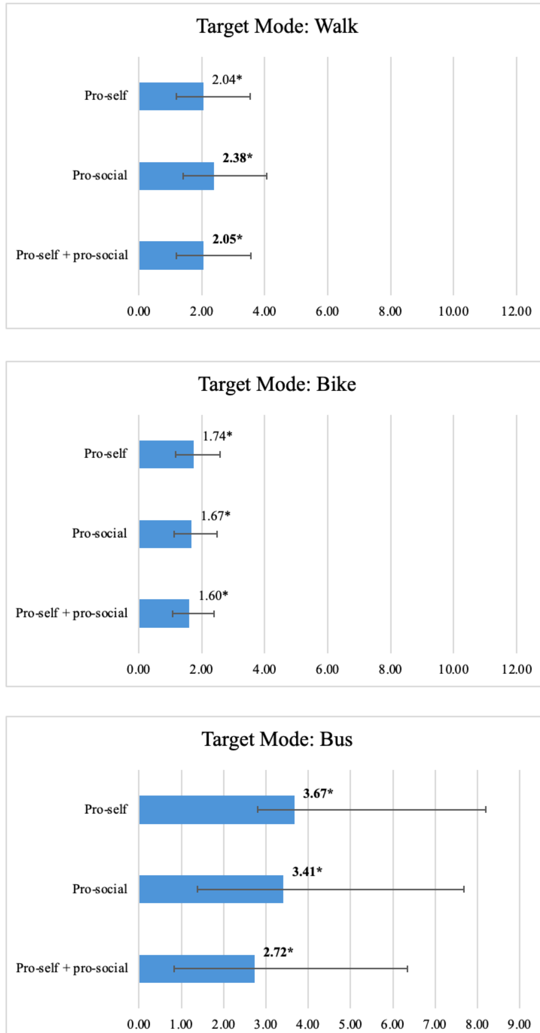


Figure 8: Likelihood (presented as odds ratio) of choosing sustainable modes in the presence of messages using emissions information compared to the control group

The effects of air quality impact messaging in promoting bus transit are illustrated in **Figure 9**. The highest impact occurred when the pro-self and pro-social benefits of choosing the bus for air quality improvement were communicated, with an odds ratio of 3.65. Similarly, communicating the pro-social message alone increased the likelihood of choosing bus transit by 3.39 times. Both the pro-social and pro-self + pro-social messages significantly impacted the likelihood of choosing bus transit, whereas the effect of the pro-self message alone was relatively low.

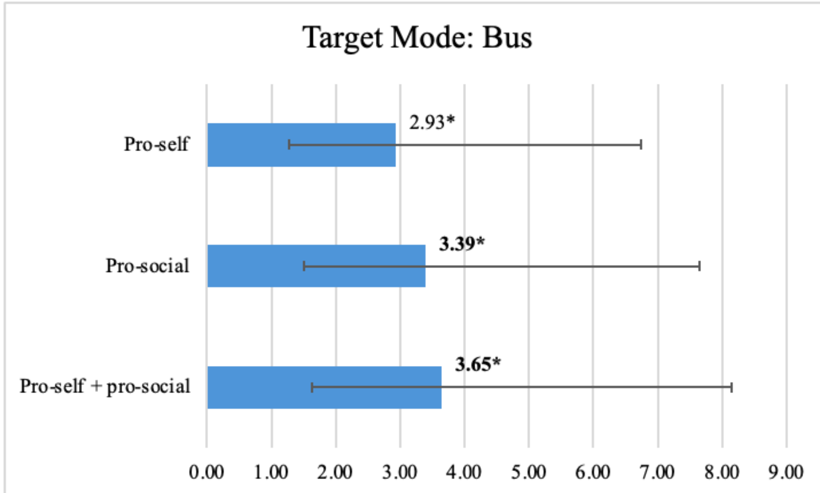


Figure 9: Likelihood of choosing bus transit in the presence of air quality impact-related messages compared to control group (odds ratio)

Figure 10 shows the effectiveness of active lifestyle messaging in promoting active travel modes. The message that combined calories burned (pro-self) with community health (pro-social) was effective in promoting walking. Considering that over 70% of participants agreed that they maintain an active lifestyle, it is not surprising that participants in this group were 3.64 times as likely to walk compared to the control group. Participants receiving a similar message highlighting only the calories burned from walking were 2.52 times as likely to walk compared to control. Participants receiving pro-self information about step counts were 2.21 times as likely to walk.

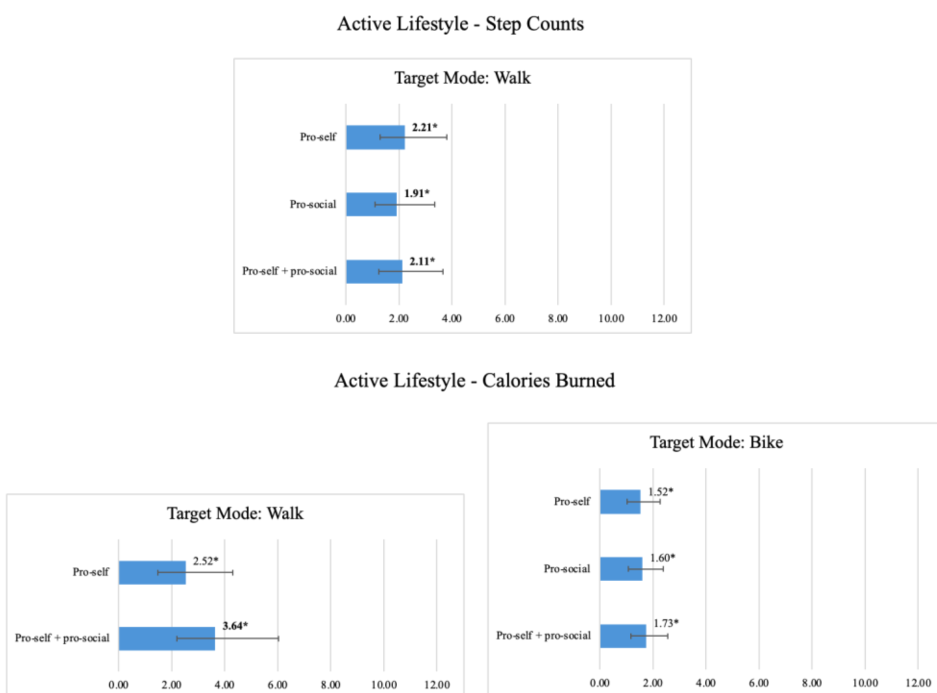
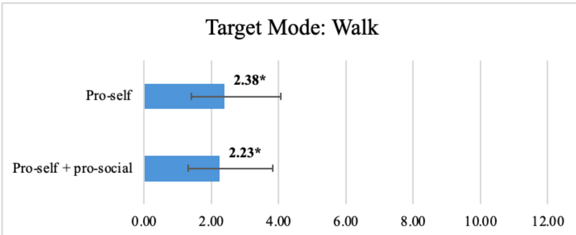


Figure 10: Likelihood of choosing walking and biking in the presence of active health-related informational messages compared to the control group (odds ratio)

The effectiveness of heart health messaging in promoting active travel modes is shown in **Figure 11**. The pro-self heart health message significantly increased participants' willingness to choose walking, with the odds of choosing to walk increasing by a factor of 2.38 compared to the control group. This could be attributed to 77.57% of participants indicating that they were health conscious.



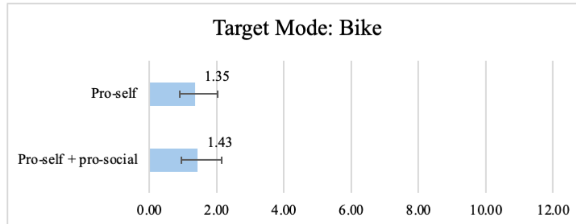


Figure 11: Likelihood of choosing walking and biking in the presence of heart health-related information messages compared to the control group (odds ratio)

2.3.3 Effects of informational messages on willingness to choose sustainable modes

The willingness to choose sustainable travel modes in the presence of informational messages is recorded using a 7-point Likert scale, ranging from "Strongly disagree" to "Strongly agree". Since the response is on an ordinal scale, the effectiveness of the messages is analyzed using an ordinal logistic model (**Equation 2**). Each informational message's effect is compared against the control group.

$$Y_n = \alpha X_n + \epsilon_n \tag{2}$$

Here, Y_n represents a latent variable that determines the discrete ordered outcomes for each participant n, X_n denotes explanatory variables, e.g., sociodemographic characteristics, and α represents the coefficients.

Based on the ordinal logistic model, all messages containing environmental information about emissions to promote bus transit are effective in increasing participants' willingness to choose bus transit, as shown in **Figure 12**. Among these, when the pro-self message was provided, the odds of willingness to choose bus transit increased by a factor of 1.27 compared to the control group. The pro-social message, as well as the combined (pro-self + pro-social) message with emissions information, was also effective in increasing willingness to choose walking. This could be attributed to 54.40% of participants expressing concern about their carbon footprint and 59.51% indicating a willingness to take action to reduce it in the 7-point Likert scale statements.

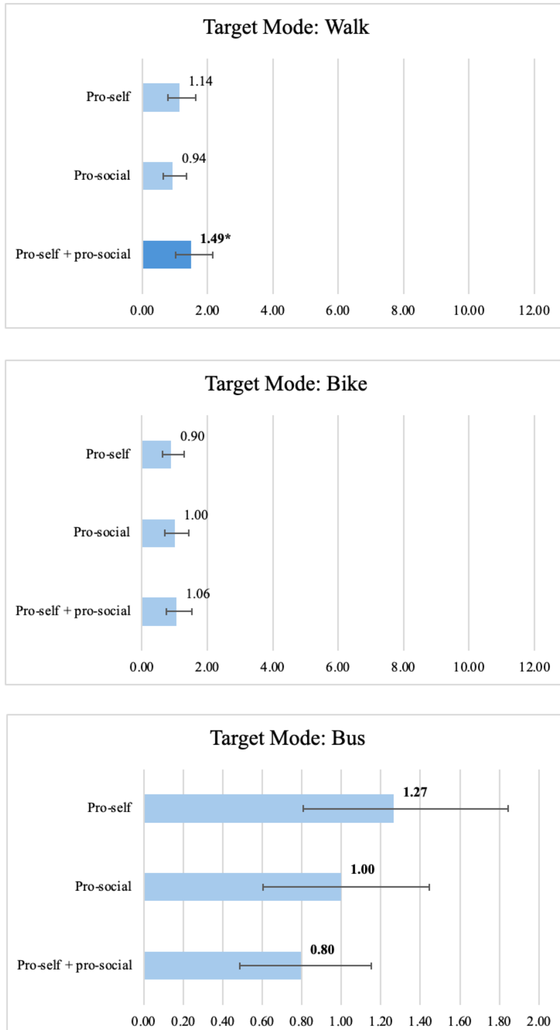


Figure 12: Likelihood of willingness to choose sustainable modes in the presence of emissions-related information messages compared to the control group (odds ratio)

All messages with environmental information about air quality are just as effective as the control group in increasing participants' willingness to choose bus transit, as shown in **Figure 13**.

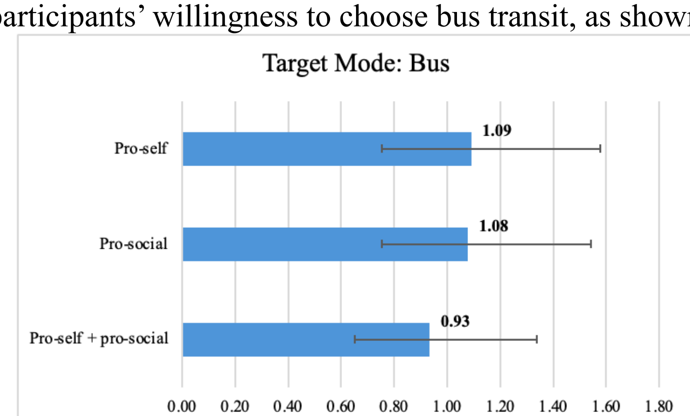


Figure 13: Likelihood of willingness to choose sustainable modes in the presence of air quality-related informational messages compared to the control group (odds ratio)

The effects of active lifestyle messaging on willingness to walk and bike are shown in **Figure 14**. Messages highlighting calories burned while walking, coupled with community health benefits, significantly increased willingness to walk (odds ratio 1.18). An informational message about step counts (pro-self) coupled with community health benefits (pro-social) produced a willingness to walk similar to the control group (odds ratio 1.05). This could be because 71.85% of participants indicated that they maintain an active lifestyle. Step counts provide a clear and measurable personal health benefit, making the message more actionable. Additionally, community health benefits may appeal to individuals' sense of social responsibility, making them more likely to walk.

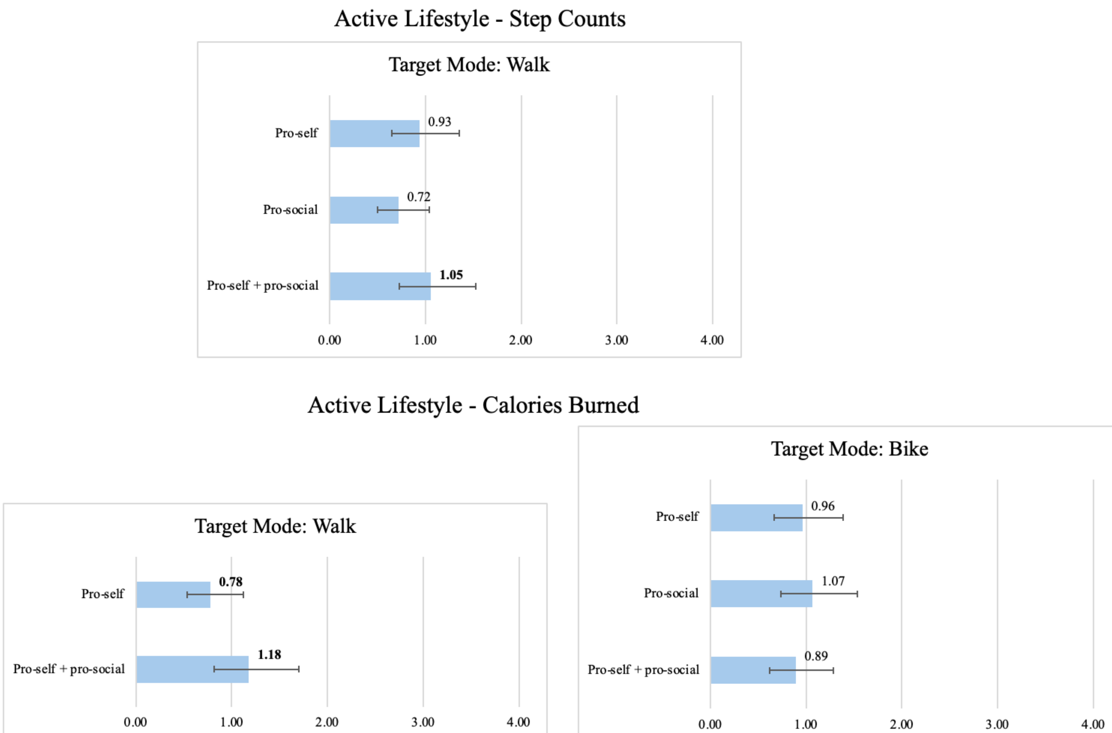


Figure 14: Likelihood of willingness to choose sustainable modes in the presence of active health-related informational messages compared to the control group (odds ratio)

All heart health messages were about as effective as no message in increasing participants' willingness to walk or bike, as shown in **Figure 15**.

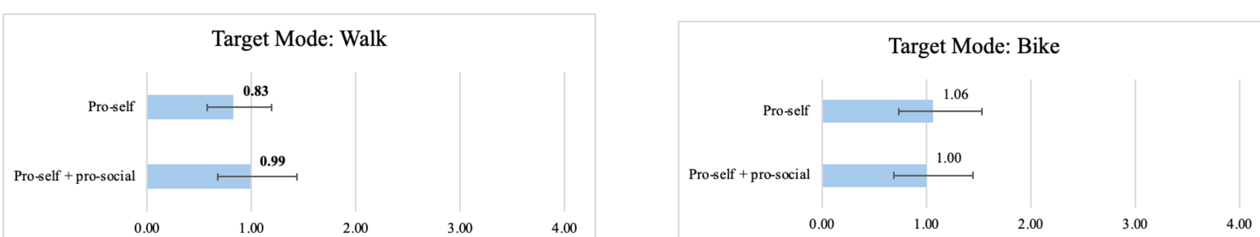


Figure 15: Likelihood of willingness to choose sustainable modes in the presence of heart health-related informational messages compared to the control group (odds ratio)

2.3.4 Effect of informational messages on choosing sustainable travel modes for non-commute trips

In every treatment group, as a follow-up to the scenario question, participants were asked whether they would choose sustainable modes for non-commute trips across six different non-commute trip types. The percentages of survey respondents choosing sustainable modes under different informational messages are plotted in **Figure 16**. A higher percentage of participants chose sustainable modes for fitness and social trips, while medical trips had a lower percentage overall. For fitness trips, the activity itself (walking or biking) aligns with the nature of the trip, making these modes naturally appealing. For instance, 61.43% of participants chose to walk for fitness trips when provided with a message illustrating the pro-self benefits in the form of step counts. Social trips, with their relaxed nature and potential for social interaction, also showed higher percentages, with 60% choosing sustainable modes under the same message. Entertainment trips also showed higher percentages of participants choosing sustainable modes (for example, 46.43% chose to walk with the same message). For entertainment trips (such as going to a concert), difficulty in finding parking spaces could lead to a higher percentage of participants choosing sustainable modes.

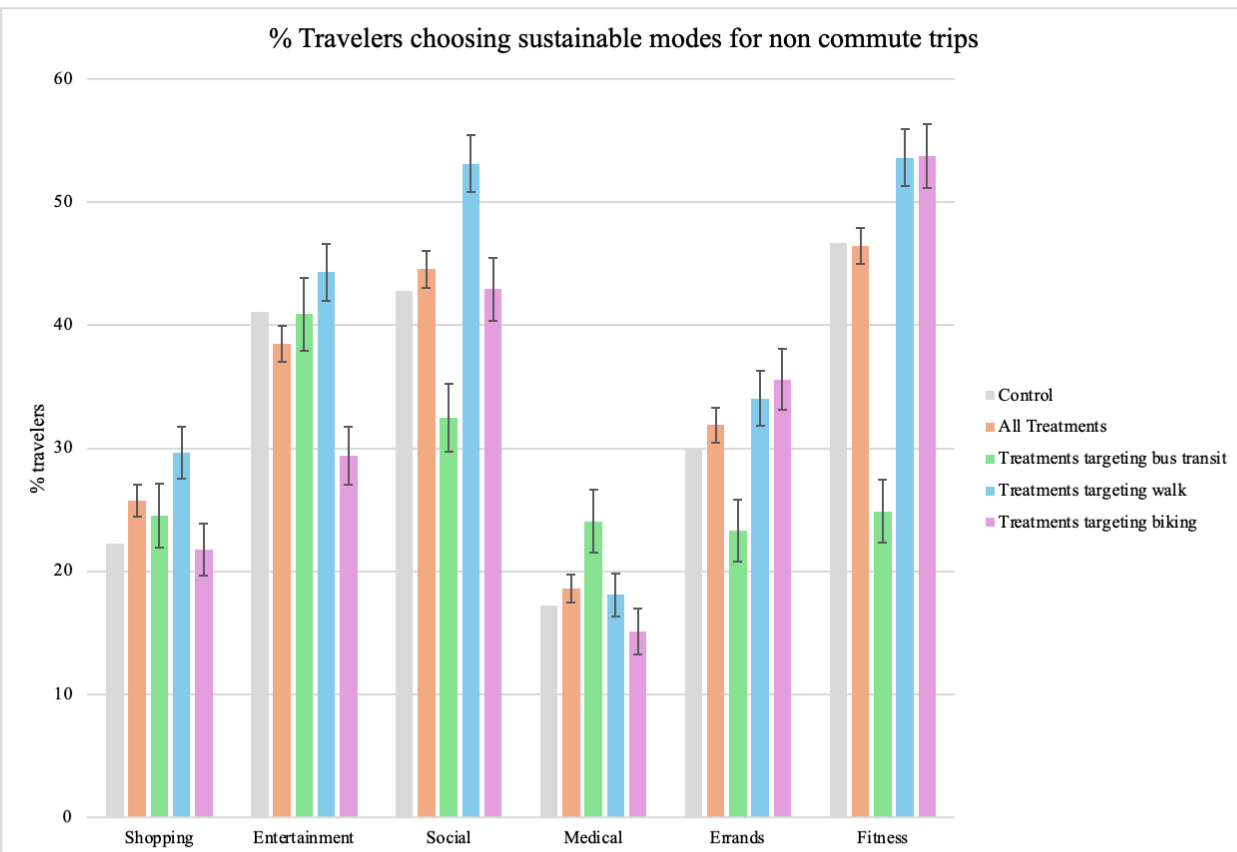


Figure 16: Percentage of travelers choosing sustainable modes for non-commute trips in the presence of health and environmental informational messages

By contrast, medical trips had a low percentage of participants choosing sustainable travel modes, as they often require a high degree of convenience and reliability, which may be perceived as lacking in sustainable modes. They can also involve a sense of urgency, which may prevent the consideration of sustainable modes with higher travel times. Next to medical trips, non-commute trips such as errands and shopping also had a lower percentage of participants choosing sustainable travel modes. Since trips related to errands and shopping may have different requirements compared to commute trips, such as flexibility, carrying capacity, and convenience, lower percentages were observed. Overall, the informational messages promoting bus transit had a lower percentage of participants choosing it across all non-commute trip types. Non-commute trips often require multiple stops or travel during off-peak hours, when transit may be considered less convenient due to lower availability and limited service areas.

2.4 Discussion

2.4.1 Informational messages with high potential to promote walking and bus transit

Information about environmental benefits highlighting emission reductions is found to be a strong contender to promote bus usage, which is consistent with prior literature (Riggs, 2020). This message had a positive effect on both the scenario-based question and the willingness to choose question to promote bus usage. Both calories burned combined with community health benefits and step counts alone were strong motivators for promoting walking. This result is consistent with prior literature in medical and behavioral evidence domains (Lee & Buchner, 2008; Takama et al., 2017; Wattanapisit & Thanamee, 2017; Williams et al., 2008).

2.4.2 Divergence between stated willingness to change versus mode choice decision

Some divergence between participants' stated willingness to change and their mode choice in scenario-based questions is observed. While the information on the benefits of reduced carbon emissions increased the participants' willingness to choose bus transit, biking, and walking, they did not choose the targeted mode except in the case of messages promoting bus transit. This divergence may stem from their own perceptions about different travel modes as well as the practical challenges they face with biking and walking, despite their willingness to change.

Another source of divergence is evident in the impact of air quality information on bus transit adoption. While the information on the pro-social, pro-self, and combined benefits of air quality increased people's willingness to take bus transit compared to the control group, none of these messages led people to choose bus when presented with various travel modes in the scenario-based questions. This could be because, although the prospect of improved air quality is an appealing benefit of choosing bus transit over private vehicles, in practice, waiting for the bus may increase people's exposure to potential air pollution.

Information provision about heart health increased people's willingness to walk, but it did not lead them to choose walking in the scenario-based questions. This may be due to practical challenges such as distance, duration, weather, and other concerns.

2.4.3 Informational messages that were ineffective

Messages aimed at promoting biking had no impact on people's willingness to bike or their selection of biking in the scenario-based choices. Biking can be perceived as physically demanding and less convenient. Moreover, due to the lack of biking infrastructure in the U.S., biking can also induce safety concerns. So, even with the informational messages illustrating the positive benefits of biking, these barriers may outweigh the perceived benefits.

Overall, messages pertaining to heart health did not have any significant impacts in promoting walking and biking, and in case of the pro-self message promoting biking, a negative effect was observed. These mixed results could be because of differing perceptions of walking and biking. Walking may be perceived as more accessible and less strenuous while biking may be perceived as less convenient and physically demanding.

2.4.4 Low-cost mobile app-based implementation

Informational messages examined in this study can be easily implemented across communities in the U.S. with low cost and high efficiency. The widespread use of mobile phones makes the implementation cost-effective for large-scale implementation compared to the traditional monetary incentive-based approaches. Moreover, previous literature (Riggs, 2020) illustrates the higher efficiency of information provision over monetary incentives. For example, the messages of giving up driving for environmental benefits received a 39% positive response, while monetary incentives had a 30% positive response (Riggs, 2020).

2.5 Conclusions

This study explores whether providing mobile app-based information on the health and environmental benefits of sustainable travel modes can influence the preferences of personal vehicle users in the U.S. A stated preference survey is conducted as a randomized control trial to investigate the effectiveness of several health and environmental informational messages in promoting sustainable modes: bus transit, walking, and biking. The study finds that health and environmental information promote bus transit and walking, though the effectiveness varies across different modes and information. Information provision about pro-self environmental benefits (emission reductions) promotes bus transit effectively. Similarly, information provision about calories burned and community health benefits are effective in promoting walking. By contrast, information provision aimed at encouraging biking is not effective.

The main limitation of this study is that it conducted a survey to assess people's stated preferences by mimicking a real-time mode choice scenario by providing participants with images of a mobile app. However, field studies are needed to validate the effectiveness of real-time health and environmental information provision in promoting sustainable modes. Stage 2 of will address this limitation leveraging the City of Peachtree Corners, GA, as a living lab.

The findings from this study highlight the importance of real-time health and environmental information provision in promoting sustainable modes, leading to real-world policy implications. For policymakers, designing and tailoring effective informational messages that highlight health and environmental benefits of sustainable travel modes is crucial for encouraging shifts from personal vehicle usage. Messages should highlight the individual benefits such as personal health and environmental impacts, as well as community health benefits. Specifically, messages promoting bus usage should incorporate information on emission reductions along with personal benefits, while messages promoting walking should prioritize information on calories burned and community health benefits. Additionally, low-cost implementation via mobile apps is scalable across the U.S., including small urban clusters and rural areas where funding is often limited. Further, to make these policies more effective in promoting biking, some supporting policies are needed to improve biking infrastructure and address specific situational factors such as safety, distance, and time constraints that may discourage travelers from choosing this mode.

3. Promoting Sustainable Travel Modes through Gamified Health and Environmental Information

3.1 Introduction

In the U.S., 82.27% of the population depends on personal vehicles for their daily travel (U.S. Census Bureau, 2021). Vehicle emissions not only negatively impact the environment (US EPA, 2024) but also have detrimental effects on public health (Zhang & Batterman, 2013), including respiratory and cardiovascular illnesses (Boogaard et al., 2022; Krzyzanowski et al., 2005; Zhang & Batterman, 2013). Widespread adoption of sustainable modes, such as transit, walking, and biking, can mitigate these negative health and environmental externalities.

Building upon the insights from **Chapter 2**, which demonstrated the potential of health- and environment-focused messaging to influence sustainable travel behavior, this chapter explores gamification as a complementary strategy to further engage travelers and reinforce positive behavioral shifts.

In recent years, there has been a rising awareness about the health and environmental benefits of sustainable modes among U.S. population (Cohen, 2022). Despite being aware of the benefits, travelers often stick to personal vehicles as their preferred mode, due to a lack of engaging information about the benefits. For instance, while platforms like Google Maps provide sustainable mode and route alternatives (i.e., routes with higher fuel savings), travelers frequently stick to their preferred modes and routes without checking for alternatives (Salonen et al., 2014; Vreeswijk et al., 2013). Therefore, health and environmental information needs to be engaging while highlighting the benefits of sustainable modes at the time of travel decision-making. Gamification can be an effective approach to presenting information about the benefits in an engaging way.

Gamification applies game design elements such as badges and leaderboards into non-game contexts (Chou, 2019). It has shown effectiveness in encouraging sustainable behaviors by increasing engagement in public health (Mamede et al., 2021; Mazéas et al., 2022; Patel et al., 2019; Sardi et al., 2017; Tesi et al., 2023), e-learning (Saleem et al., 2022), energy conservation (Casals et al., 2020; Csoknyai et al., 2019), waste management (Soares et al., 2024), and water usage (Paolo & Pizziol, 2024). Implementing energy conservation using gamification elements, such as points and social comparisons, has increased conservation behavior in residential (Casals et al., 2020; Csoknyai et al., 2019) and office spaces (Oppong-Tawiah et al., 2020). In public health, several studies have explored the use of gamification to increase physical activity (Mamede et al., 2021; Patel et al., 2019). For example, a study found that gamification is effective in promoting physical activity in both healthy participants and participants with chronic diseases (Mazeas et al., 2022). Moreover, fitness apps, which offer badges and leaderboards to motivate users, have been found effective in increasing physical activity (Laranjo et al., 2021).

In transportation literature, a study found that the popular gaming app Pokemon Go, which sends the users to different quests to earn badges, impacts users' daily travel habits (Guo et al., 2022). A preliminary study on gamification to encourage active modes (walking and biking) has shown promising results (Harris & Crone, 2021). However, these studies did not leverage real-time gamified health and environmental information to promote sustainable modes. This study investigates the impact of real-time gamification elements, specifically badges and leaderboards, on promoting bus transit, walking, and biking. Metrics such as distance traveled by sustainable modes, step counts and calories burned through active modes, and emissions avoided through the adoption of sustainable modes are gamified.

Badges are visual elements that are found to be effective due to their clear descriptions of goals and personal milestones, which can foster intrinsic motivation and provide a sense of achievement (Hamari, 2017). By contrast, leaderboards can influence outcomes by stimulating social engagement and competition, as shown by studies indicating improved performance (Domínguez et al., 2013; Landers et al., 2017) and increased participation (Farzan et al., 2008) in various contexts. Prior literature showed positive results for gamification in the form of health information, such as step counts (Mamede et al., 2021; Patel et al., 2019) and calories burned (Deery et al., 2019) as well as environmental metrics like emission reductions (Douglas & Brauer, 2021).

This study leverages gamified health and environmental information in the context of daily travel and designs several behavioral interventions to test their effectiveness in promoting sustainable modes. In travel behavior literature and practice, tolling and congestion pricing have been found to be effective in reducing personal vehicle usage. However, these approaches are considered inequitable due to their negative impact on disadvantaged groups, including low-income individuals (Jaensirisak et al., 2005; Weinstein & Sciara, 2006). Recent strategies to encourage sustainable modes and routes, such as monetary incentives, overcome the equity issues associated with tolling but are unsustainable due to limited funding (Farooqui et al., 2014; T. Li et al., 2021). The behavioral interventions tested in this study are equitable and unlike monetary incentives, they do not suffer from limited funding issues. Moreover, the widespread adoption of mobile devices can be leveraged to deliver these real-time trip-specific gamified health and environmental information, making this approach cost-effective and scalable across the U.S.

This study uses a stated preference survey design that simulates real-world mode choice scenarios to test the effectiveness of different gamification interventions in promoting sustainable modes. The rest of the chapter is organized as follows: Section 3.2 elaborates the methods, Section 3.3 illustrates the results, Section 3.4 discusses the results and offers insights, and Section 3.5 presents concluding remarks.

3.2 Methods

3.2.1 Survey design

In this study, interventions corresponding to gamified health and environmental information are examined to promote sustainable travel modes: bus transit, walking, and biking. A stated preference survey design is employed to test the effectiveness of these interventions. The study is approved by the Georgia Tech's Institutional Review Board (#H23240). Participants were recruited via the Prolific survey data collection platform, with eligibility criteria being 18 years or older, residing in the U.S., and primarily personal vehicle users. **Figure 17** shows the survey flow. The survey has three main sections. The first section comprises sociodemographic questions, such as age, gender, and income. The second section focuses on a 7-point Likert scale travel preference question ranging from 1 (strongly disagree) to 7 (strongly agree), which is used to gather opinions on various statements related to health and environment, as outlined in **Table 6**. The final section presents scenario-based stated preference questions to investigate participants' travel choices under the interventions.

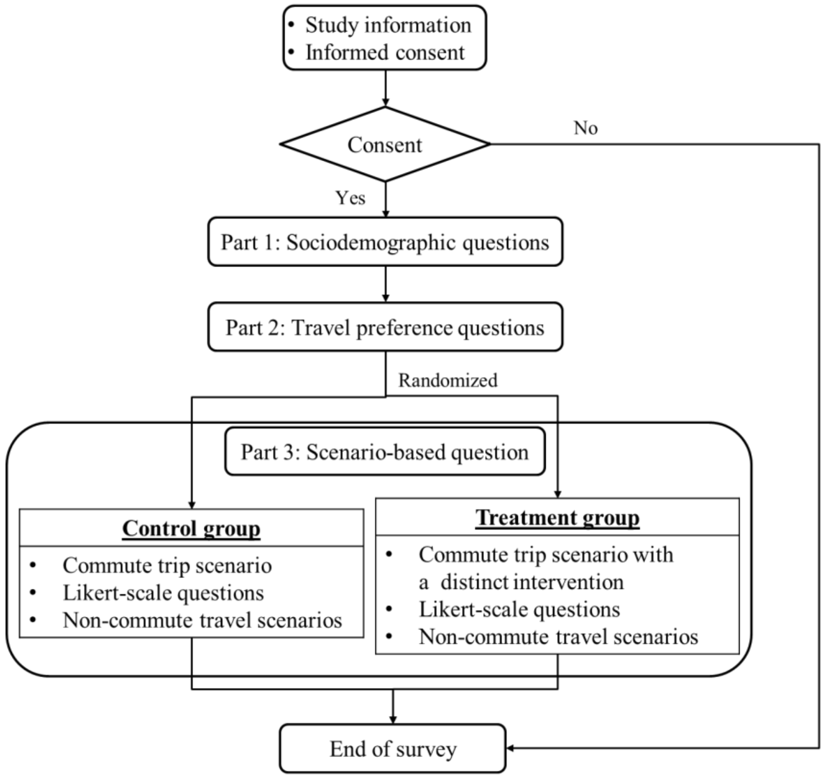
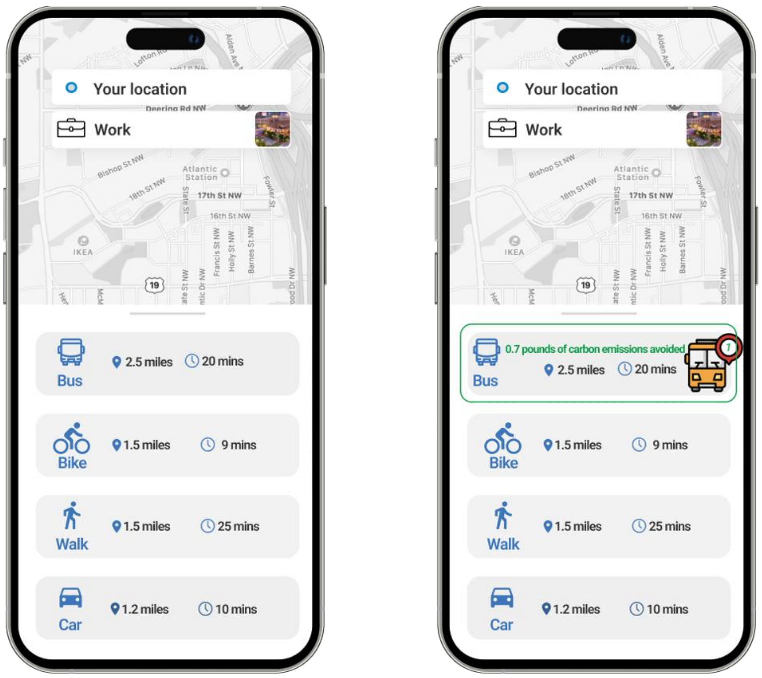


Figure 17: Survey Flow

Table 6: Likert scale opinion questions

Likert scale statement	**Intent**
"I am concerned about my carbon footprint"	Concern about individual carbon footprint
"If I knew how to better reduce my carbon footprint, I would take action"	Willingness to take action to reduce carbon footprint
"I maintain an active lifestyle"	Level of physical activity
"I am health conscious"	Health consciousness
"When making decisions, I consider the opinions or approval of others around me"	Social validation

Scenario-based stated preference questions present participants with a hypothetical commute scenario. A customized image of a mobile app, which replicates a real-time travel decision-making with travel alternatives and interventions, is used as illustrated in **Figure 18**.



A. Control B. A treatment example

Figure 18: Examples of customized images used in the scenario-based questions

Two different types of gamification elements, badges and leaderboards, are used in this study. Participants were instructed to assume that all travel options presented in the customized image are available to them. Along with this, prompts specific to badges and leaderboards were provided accordingly. An example prompt for a badge is "Suppose badges are awarded for the distance traveled by bus transit. In this scenario, you can earn the next badge by completing this trip using bus transit". An example prompt for leaderboard is "Suppose a leaderboard keeps track of bus transit users in your community and ranks them based on distance traveled using bus transit. In this scenario, you can move up the leaderboard by completing this trip using bus transit". As shown in Figure 2, travel attributes (available alternative modes, travel times, and travel distances) presented to the participants remain the same across all groups with the interventions varying across the treatment groups. As a follow-up to the scenario-based question, participants are asked to rate the following two statements on a 7-point Likert scale ranging from 1 (strongly disagree) to 7 (strongly agree): (i) "The badge (or leaderboard) is relevant to me" and (ii) "I would change my behavior based on the intervention". Additionally, participants are asked whether they would consider using sustainable modes for different types of non-commute trips.

3.2.2 Behavioral interventions

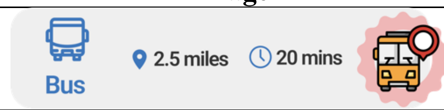
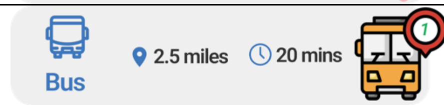
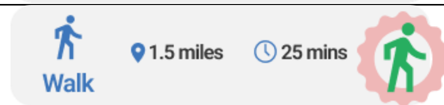
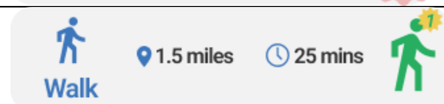
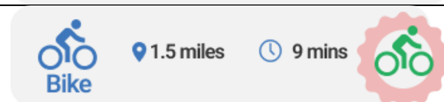
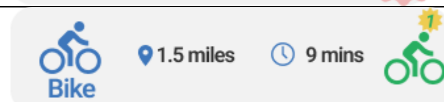
Several interventions are designed based on the following categories of information coupled with gamification elements, which are elaborated in the following subsections:

- Distance traveled
- Active health metrics – step counts
- Active health metrics – calories burned
- Environmental metrics – emissions

3.2.2.1 Gamification based on distance traveled by sustainable modes

This set of interventions, shown in **Table 7**, incorporates information about distance traveled using sustainable travel modes along with gamification elements to encourage the adoption of sustainable modes.

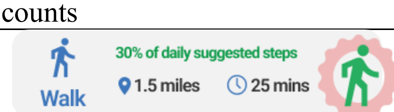
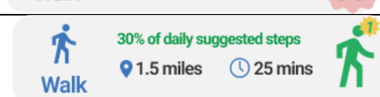
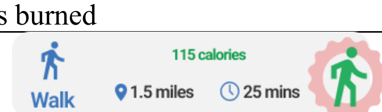
Table 7: Gamification based on distance traveled

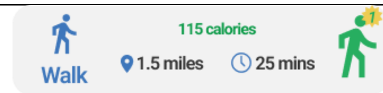
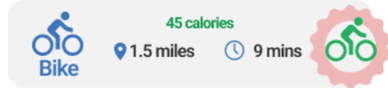
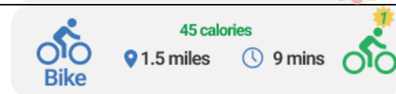
Category	Target mode	Image
Badge	Bus	
Leaderboard	Bus	
Badge	Walk	
Leaderboard	Walk	
Badge	Bike	
Leaderboard	Bike	

3.2.2.2 Gamification using active health metrics

Two interventions are designed by combining gamification elements with step counts in a particular trip in relation to daily suggested steps, i.e., 10,000 steps a day (Wattanapisit & Thanamee, 2017). Four additional interventions are designed to incorporate badges and leaderboards with calories burned information to motivate travelers to choose walking and biking. These interventions are shown in **Table 8**.

Table 8: Gamification using active health metrics

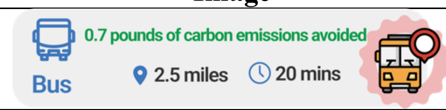
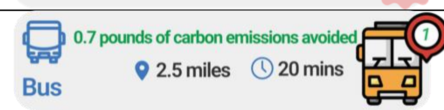
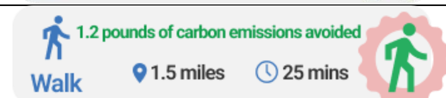
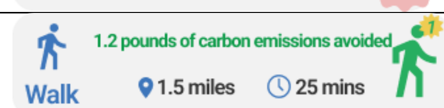
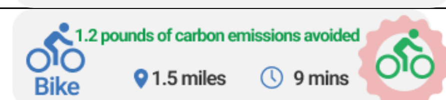
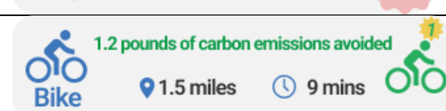
Category	Target mode	Image
Step counts		
Badge	Walk	
Leaderboard	Walk	
Calories burned		
Badge	Walk	

Leaderboard	Walk	
Badge	Bike	
Leaderboard	Bike	

3.2.2.3 Gamification using environmental metrics

This set of interventions gamifies information about emissions avoided by choosing sustainable modes over personal vehicle travel. **Table 9** presents these interventions.

Table 9: Gamification using environmental metrics

Category	Target mode	Image
Badge	Bus	
Leaderboard	Bus	
Badge	Walk	
Leaderboard	Walk	
Badge	Bike	
Leaderboard	Bike	

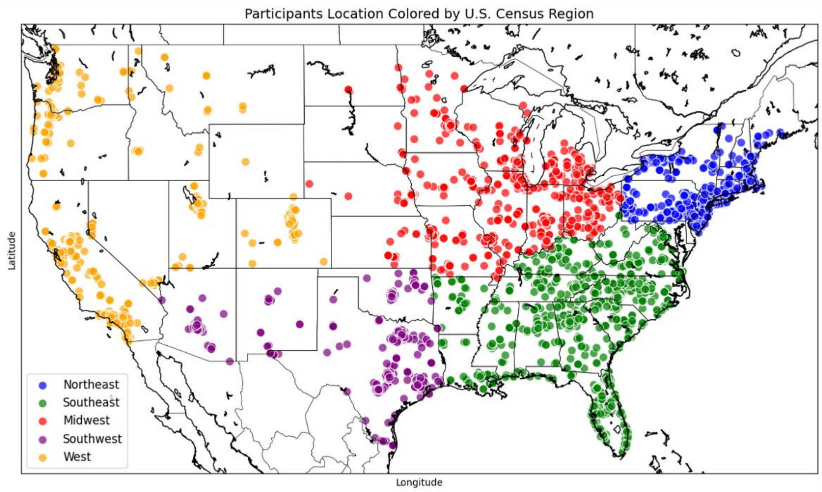
3.3 Results

Over the 2024 summer travel season, a sample of 4,469 U.S. personal vehicle users completed the survey. The participants were randomly assigned to one of the 25 groups (24 treatment and 1 control groups). The groups were comparable in terms of their sociodemographic characteristics as revealed by a one-way ANOVA.

Overall, the participants rated positively across various Likert scale statements listed in **Table 6**. Specifically, 73.65% of the participants indicated that they are health conscious, and 69.25% indicated that they maintain an active lifestyle. Overall, 61.11% of participants expressed concern about their carbon footprint, and 71.32% indicated a willingness to take action to reduce it.

3.3.1 Descriptive statistics

The distribution of survey participants across the U.S. Census regions (Southeast, Midwest, West, Northeast, Southwest) is shown in **Figure 19**.



Region	% participants
Southeast	30.93
Midwest	24.81
West	16.64
Northeast	14.72
Southwest	12.90

Figure 19:Participant locations by U.S. Census Region

Similar to Chapter 2, the participants are evenly split by sex with 49.7% females and 49.6% males as shown in **Figure 20**.

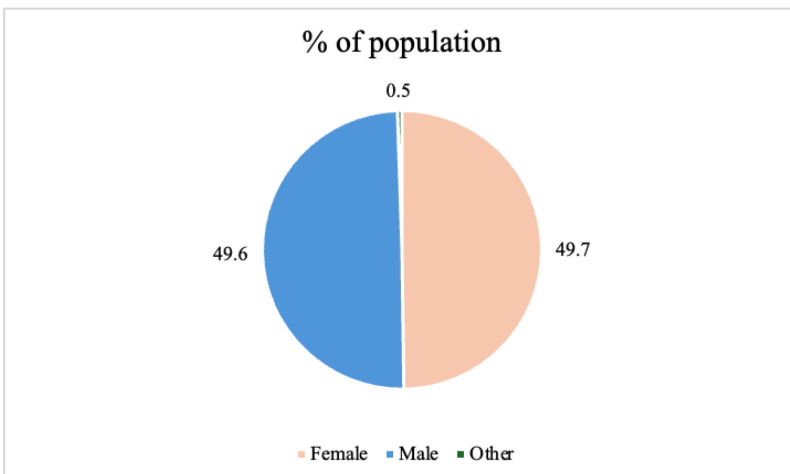


Figure 20:Distribution of female and male among the survey participants

Similarly, the age distribution of the survey participants is skewed toward middle age, with over 70% between 30 and 59 years old, as shown in **Figure 21**. The largest share of participants is between 40 and 49 years old. Younger adults aged 29 and below accounted for 14.8% of the sample, whereas the percentage of older adults was relatively low (2.1% aged 70 and above). The Prolific survey platform had relatively few participants aged 60 and above in its participant pool.

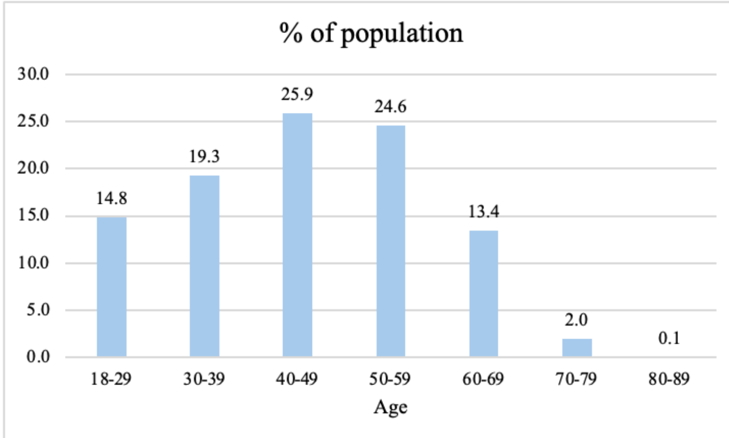


Figure 21: Percentage of participants by age in the survey sample

Figure 22 shows that the income distribution is slightly skewed, with 44.9% of participants reporting an annual household income of $80,000 or higher and only 17.1% reporting income lower than $29,000. This trend is similar to the participant distribution in the informational messages survey.

Figure 22: Percentage of participants by income level in the survey sample

The reported Likert-scale ratings to questions listed in Table 5 about participants' opinions on health, environment, and willingness to take action are presented as a stacked bar chart in **Figure 23**. These ratings revealed generally positive sentiments (somewhat agree, agree, or strongly agree) toward health and the environment. 73.65% of participants rated somewhat agree or higher on the health consciousness statement, and 69.25% rated somewhat agree or higher on the active lifestyle statement, indicating a strong personal health orientation. While 61.11% of participants indicated concern for their carbon footprint, more than 71.32% were willing to take action to reduce it. Similarly, over 75.94% of participants were willing to take action to improve their air quality. Overall, more than 56% of participants were willing to change their daily commute or non-commute modes.

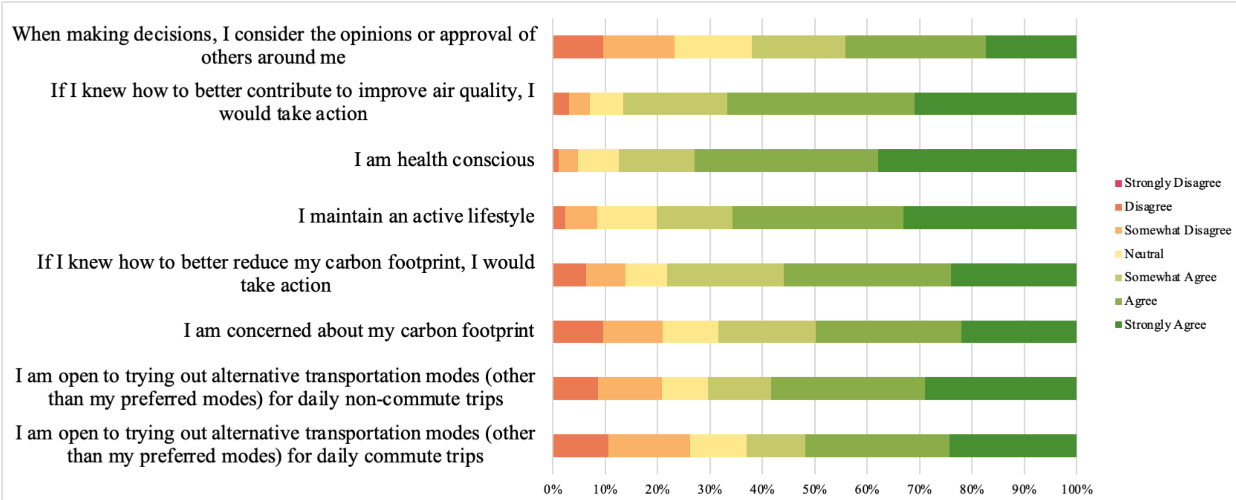


Figure 23: Participants response to health and environmental opinions

3.3.2 Effectiveness of gamification interventions in promoting sustainable modes

As the responses are categorical dependent variables, a multinomial logistic regression model (**Equation 3**) is used to capture the impact of gamification interventions on mode choice in the scenario-based questions. The regression model uses personal car as the baseline choice and each intervention's effect is compared against the control group.

$$U_n = \beta X_n + \epsilon_n \qquad (3)$$

Here, U_n is the utility for participant n, X_n corresponds to the explanatory variables, β represents the coefficients, and ϵ_n is the error term.

The effectiveness of interventions that showcase only health and environmental metrics is presented in **Figure 24** below. While the likelihood of choosing a sustainable mode is greater than 1 compared to the control group across all target modes and metrics, the coefficients themselves are not statistically significant. This indicates that the metrics alone are not sufficient motivators for promoting sustainable modes.

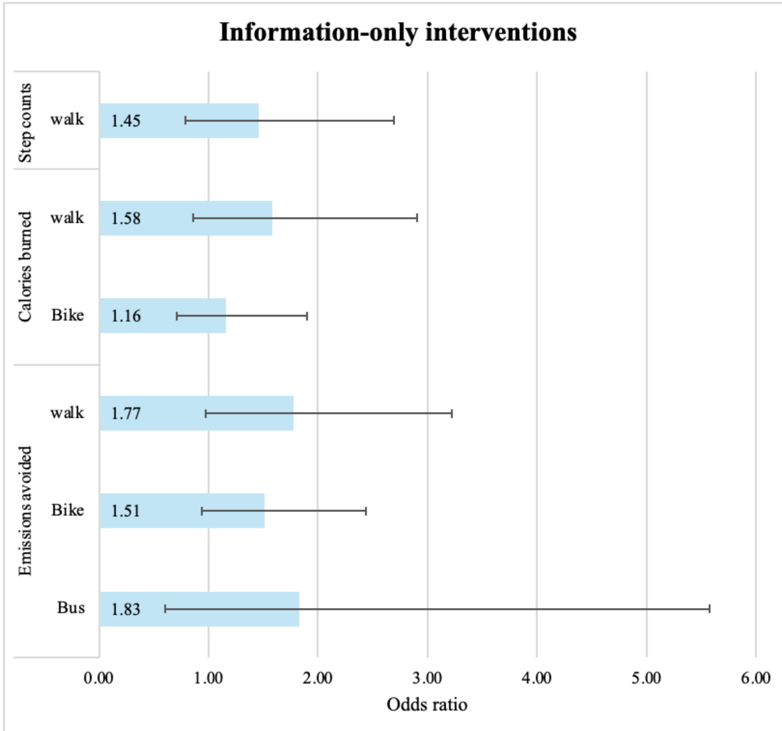


Figure 24: Effectiveness of health and environmental metrics-only interventions (without gamification elements) on likelihood of choosing targeted sustainable modes (odds ratio)

Almost all interventions that used gamified distance traveled promote sustainable travel modes effectively, with badges being consistently more effective than leaderboards (shown in **Figure 25**). Participants receiving badges and leaderboards based on distance traveled are 6.34 and 5.99 times as likely to choose bus transit, respectively, compared to the control group. Further, participants are found to be 2.95 and 2.39 times as likely to choose walking with badge and leaderboard, respectively, compared to the control group. Participants receiving badges based on distance traveled are 2.38 times as likely to choose biking, while the leaderboard does not have an effect. Since distance traveled can be substantially different for different travelers due to factors such as typical distance to work, they may find it more suitable to track personal travel and progress through badges rather than comparing with others through leaderboards.

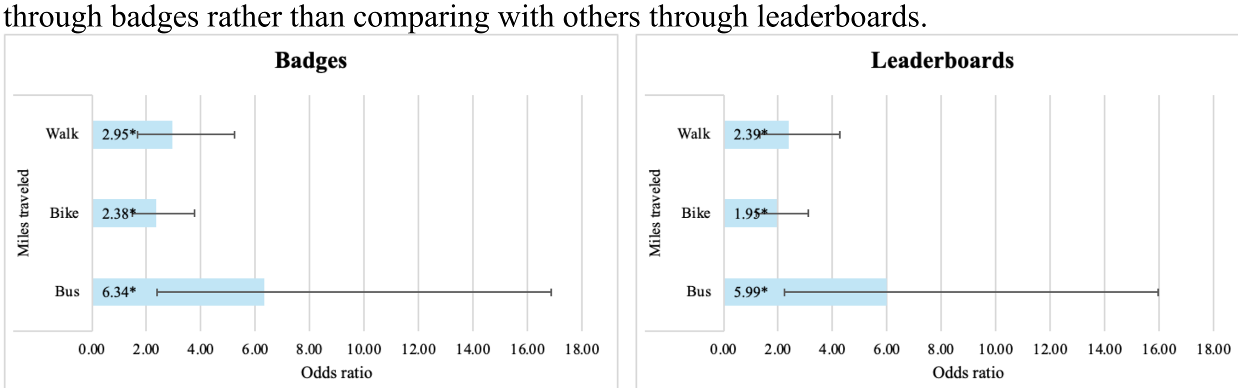


Figure 25: Effectiveness of gamification elements (badges and leaderboards) based on miles traveled on targeted sustainable modes (odds ratio)

Figure 26 shows that badges based on environmental metrics effectively promote bus transit (7.09 times), walking (2.98 times), and biking (3.06 times). Badges motivate individuals through personal milestones and visible progress, while leaderboards foster social competition by allowing individuals to compare themselves with others. Given that 58.02% of participants indicated that they care about the opinions of others when making decisions and 61.11% indicated that they would take action to reduce their carbon footprint, it is not surprising that interventions based on gamified environmental information are effective.

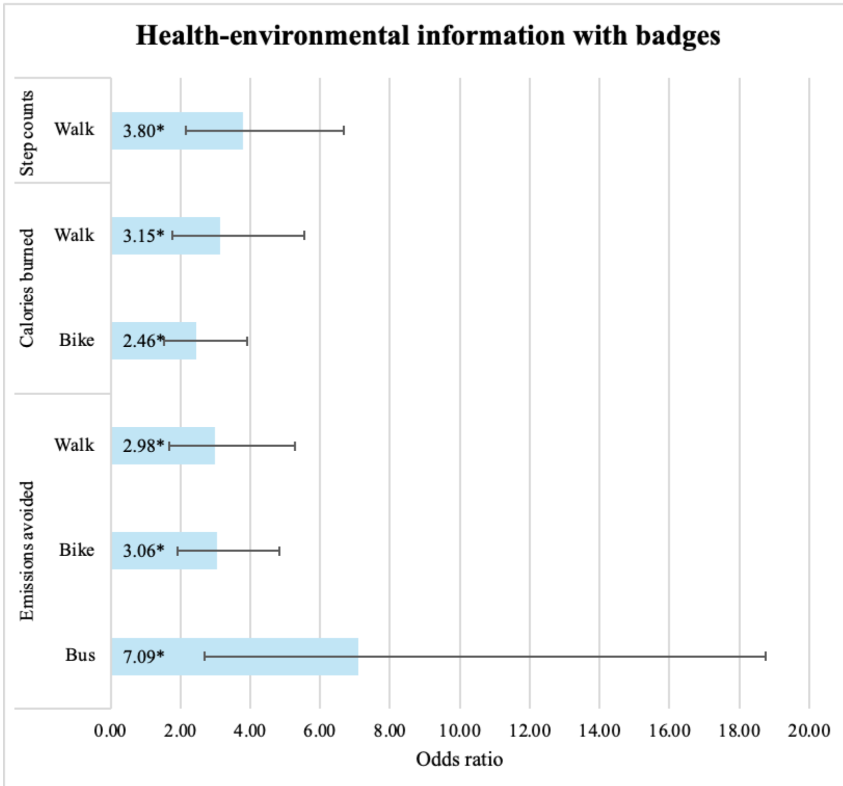


Figure 26: Effectiveness of health and environmental information along with badges on stated sustainable choice (odds ratio)

Figure 27 shows that gamification can positively impact the adoption of sustainable modes. The most effective intervention is the leaderboard based on environmental metrics (i.e., emissions avoided) to promote bus transit. Participants in this group were 5.72 times as likely to choose bus transit compared to the control group. Over 40% of participants receiving this intervention considered leaderboards to be relevant information. Similarly, participants receiving a leaderboard based on environmental metrics to promote walking were 2.3 times as likely to choose walking compared to the control group. Therefore, both badges and leaderboards based on environmental metrics significantly encourage bus transit and walking.

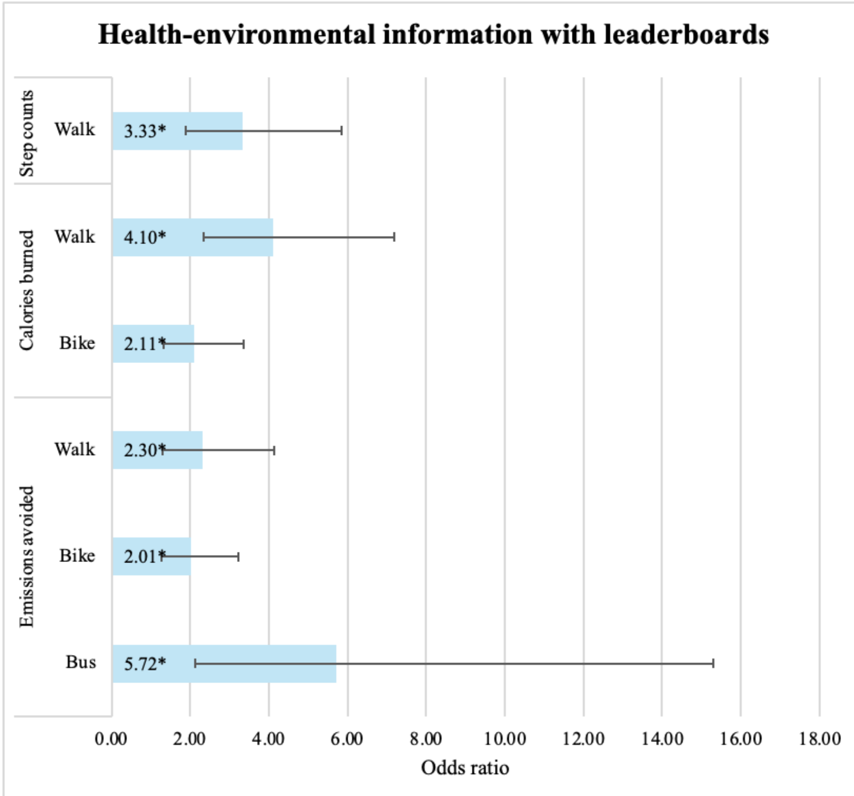


Figure 27: Effectiveness of health and environmental information along with leaderboards on stated choice (odds ratio)

Gamified active health metrics (step counts and calories burned) promote walking effectively, with leaderboards presenting a larger effect than badges. Specifically, participants receiving step counts information were 3.33 times and 3.8 times as likely to choose walking with a leaderboard and a badge, respectively, compared to the control group. Travelers receiving gamified information about calories burned were 4.10 times and 3.15 times as likely to choose walking with a leaderboard and a badge, respectively, compared to the control group. Over 53% of participants receiving step counts information and over 46% receiving calories burned information in the form of leaderboards to promote walking indicated that leaderboards were relevant to them. Both step counts and calories burned are measurable metrics, making them easier for individuals to use for self-comparison. Leaderboards are more effective than badges in promoting walking most likely because walking is a more accessible mode that can better leverage social comparison, competition, and recognition to sustain individuals' engagement.

Participants receiving badges based on calories burned were 2.46 times as likely to choose biking compared to the control group. Unlike walking, which is easier to integrate into daily commutes, biking can be considered a more strenuous activity, and the amount of effort required varies across individuals. Hence, badges may be better suited for promoting biking, as they track personal progress and achievements rather than requiring comparison with others.

3.3.3 Effectiveness of gamification interventions on willingness to choose sustainable modes

As the responses are ordinal dependent variables (7-point Likert scale, ranging from "Strongly disagree" to "Strongly agree"), an ordinal logistic regression model (**Equation 4**) is used to capture the impact of gamification interventions on willingness to choose sustainable modes in the follow-up to the scenario-based questions. Each intervention's effect is compared against the control group.

$$Y_n = \alpha X_n + \epsilon_n \tag{4}$$

Here, Y_n is a latent variable used to determine the ordered outcomes for the willingness to choose sustainable modes for participant n, X_n corresponds to the explanatory variables, α represents the coefficients, and ϵ_n is the error term.

Overall, health and environmental metrics only interventions are just as effective as no interventions in increasing participants' willingness to choose sustainable travel modes, as shown in **Figure 28**.

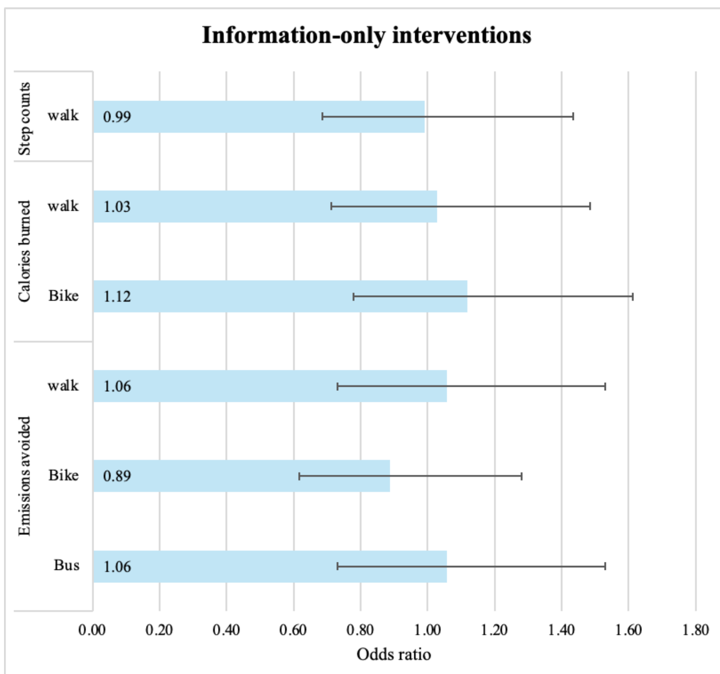


Figure 28: Effectiveness of health and environmental information-only interventions (without gamification) on willingness to choose sustainable modes (odds ratio)

While gamification elements based on miles travelled had a positive impact on the stated travel choice, its effects on stated willingness to choose sustainable modes are non-existent as shown in **Figure 29**.

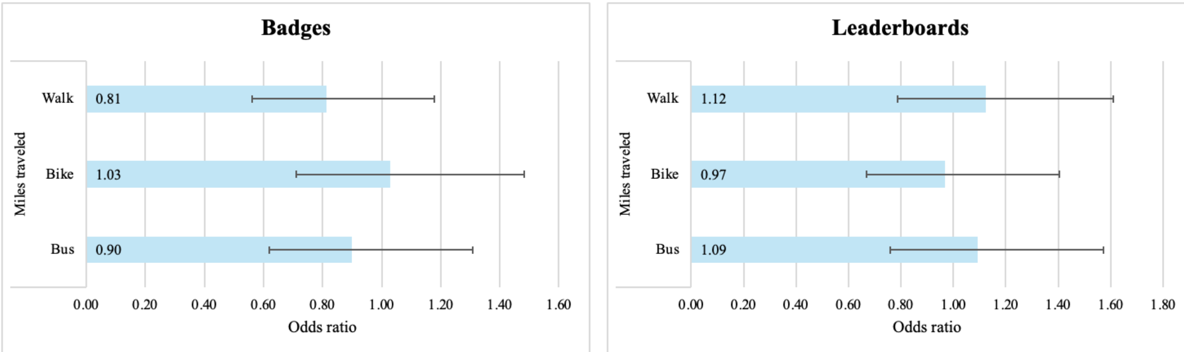


Figure 29: Effectiveness of gamification elements (badges and leaderboards) based on miles traveled on willingness to choose sustainable modes (odds ratio)

Badges based on health and environment information had a positive effective on stated choice, but had a negative effect on willingness to change as shown in **Figure 30**. Although this effect is insignificant, the trend indicates that participants underestimate their self-reported willingness to change.

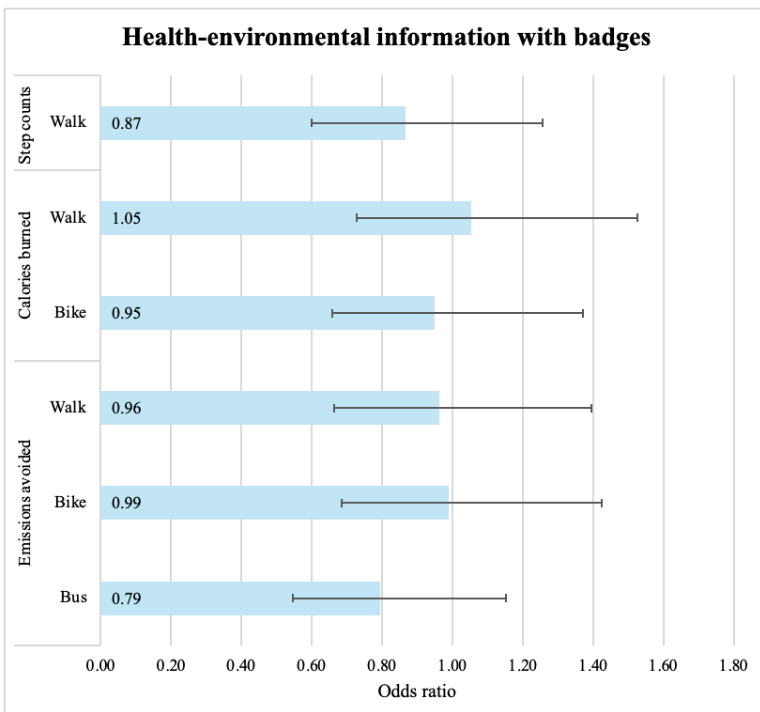


Figure 30: Effectiveness of badges based on health and environmental information on participants' willingness to choose sustainable modes (odds ratio)

Similar to badges, leaderboards (**Figure 31**) also had a negative impact on willingness to change, however this effect is insignificant.

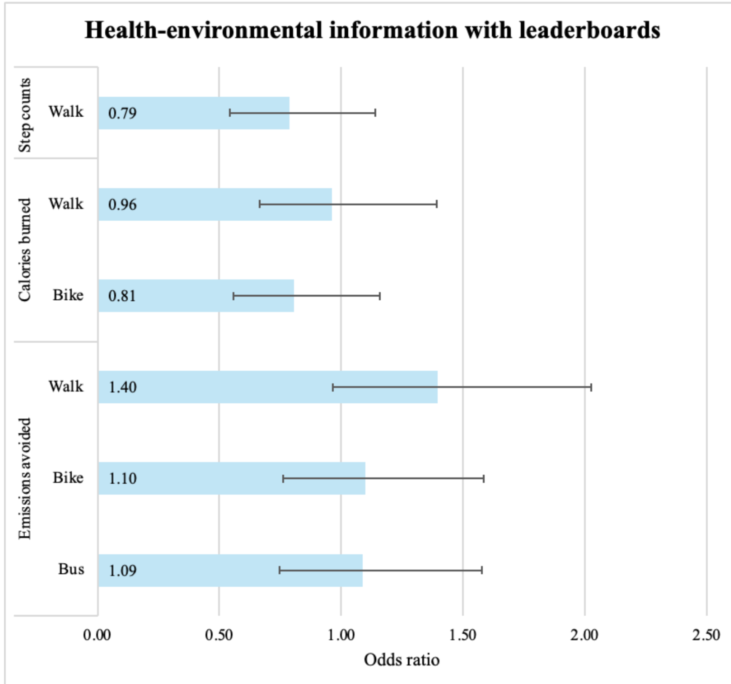


Figure 31: Effectiveness of leaderboards based on health and environmental information on participants' willingness to choose sustainable modes (odds ratio)

3.3.4 Impact of gamification interventions on non-commute trips

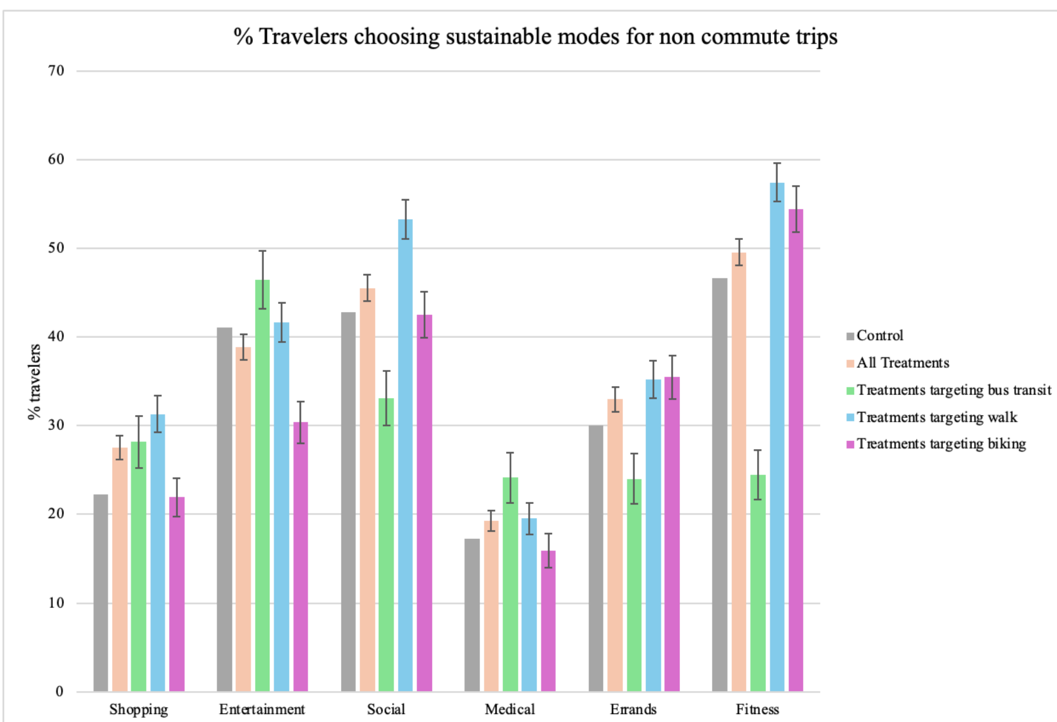


Figure 32: Percentage of survey respondents choosing sustainable modes for different non-commute trip types in the presence of gamification interventions

As a follow-up to the scenario-based question, participants were asked whether they would consider using sustainable modes for six different types of non-commute trips: shopping, entertainment, social, fitness, medical, and errands. **Figure 32** plots the percentage of survey respondents choosing sustainable modes under different gamification interventions. Across all interventions, people were more likely to use sustainable modes during their fitness or social trips, while they showed less flexibility when it came to medical trips. Fitness trips observed the highest percentages of participants using sustainable travel modes across all interventions. For instance, 57% of participants receiving gamified information on calories burned in the form of a badge and 63% of participants receiving gamified step count information in the form of a leaderboard indicated that they would choose walking for fitness trips. Active travel modes such as walking and biking already align with the purpose of fitness trips. Moreover, personal accomplishment and competition may align with individuals' fitness goals.

Similarly, social and entertainment trips also observed high percentages across all intervention groups. For instance, when presented with gamified calories burned information in the form of badges and leaderboards, 51% and 53% of participants chose to walk for social trips, respectively. The fun and gamified nature of the interventions makes alternative travel modes more appealing for social trips. Additionally, the flexible nature of these trips allows individuals to try out alternative travel modes and earn badges or move up the leaderboard.

Practical constraints such as carrying groceries or bags associated with shopping and errands may have limited the appeal of choosing sustainable modes. Medical trips had the lowest percentage of participants (e.g., only 13% of the participants that received gamified calorie counts in the form of leaderboards) choosing sustainable modes as these trips need a level of comfort and privacy which these cannot offer. Overall, across all the interventions and all the non-commute trip types, interventions promoting bus usage observed a lower percentage of people choosing the mode. Typical non-commute trip types can have trip chaining where individuals may have more than one stop. Inconvenient bus schedules, wait times, or indirect routes may have led to a lower percentage of participants choosing bus transit.

3.4 Discussion

3.4.1 Gamification interventions that were effective in promoting sustainable modes

Results showed that incorporating a leaderboard with health information such as step counts and calories burned can significantly promote walking. These interventions were effective in promoting walking as a travel mode in the scenario-based question as well as in the willingness to choose question. This is consistent with prior literature that demonstrates how leaderboards can effectively increase engagement levels (Fotaris et al., 2016; Huang & Hew, 2015; Landers et al., 2017). Using a leaderboard with emission information greatly enhanced participants' inclination to opt for bus transit and walking in scenario-based question as well as in the willingness to choose question, whereas badges with emission information were more effective in encouraging biking.

3.4.2 Divergence between selected modes and stated willingness to choose sustainable modes

Despite participants expressing reluctance to change behaviors when presented with gamified distance traveled information in the willingness to change question, nearly all of these interventions observed an increased adoption of sustainable modes in the scenario-based questions. Similarly, participants showed reluctance to the gamified health information in the form of badges in the willingness to choose walking or biking questions, but all of these interventions increased the adoption of these modes in the scenario questions. This may be because people often underestimate their willingness to change when initially confronted with new information but later start to engage with the information and find it motivating.

3.4.3 Gamification interventions that were not effective in promoting sustainable modes

Interventions using leaderboards were not effective in promoting biking. The active health intervention related to calories burned in the form of a leaderboard, aimed at promoting biking, had no impact on participants' willingness to biking or their selection of biking in the scenario-based questions. Similarly, the environmental information, combined with a leaderboard, had no impact on participants' willingness to bike or their choice in the scenario-based question. Lack of necessary infrastructure, related safety concerns, and effort required to bike can lead to varying perceptions towards biking, making competition with others less motivating, which may have rendered leaderboards ineffective.

3.4.4 Deployment in the real-world

Gamified health and environmental information tested in this study can be cost-effectively implemented across communities in the U.S. The pervasive presence of mobile devices further enhances the cost-effectiveness of this approach, making it scalable and easily deployable through mobile apps. Unlike existing travel behavior strategies (e.g., monetary incentives) that require substantial monetary investments, this approach can be particularly beneficial to disadvantaged communities that are often limited by funding.

3.5 Conclusions

This study used stated preference survey design to test the effectiveness of gamified health and environmental information to promote sustainable modes. The results indicate that leaderboards, which are linked to social competition, are stronger motivators in promoting bus transit and walking. Incorporating a leaderboard with active health information such as step counts and calories burned significantly promoted walking, while a leaderboard with environmental information (i.e., emissions avoided) promoted bus transit and walking. Badges along with environmental information and calories burned were found to be effective in promoting biking.

Two limitations are noted in this study. First, a survey is carried out to evaluate participants' stated preferences by simulating a real-time travel mode choice scenario with images of a mobile app. However, field studies are necessary to evaluate the real-world impact of providing gamified information on fostering sustainable travel modes (being addressed in Stage 2). Second, both gamification elements are longitudinal in nature, where badges are received over time and leaderboard positions can vary day to day. However, the study only measures a one-shot effect of providing these interventions rather than measuring the persistent effects.

To promote sustainable travel modes in the long term, policymakers should consider incorporating badges and leaderboards with health and environmental information. In addition, supporting policies should focus on building and maintaining extensive walking and biking infrastructure that is safe and connected. While implementing leaderboards in a community, campaigns involving community leaders and influencers can be initiated to highlight the benefits and popularity of sustainable modes, creating a positive peer atmosphere.

4. Promoting Sustainable Travel within Communities through Emerging Mobility Solutions

4.1 Introduction

Traditional fixed-route transit systems often struggle to meet the evolving mobility needs of communities. These limitations are not confined to low-density or rural areas; even in denser urban settings, gaps in service coverage, frequency, and connectivity can restrict access to essential destinations. In such contexts, personal vehicles frequently become the default mode of travel, reinforcing dependency on private transportation and limiting opportunities for mode shift.

Earlier chapters of this report focused on behavioral interventions designed to encourage more sustainable travel choices. These interventions were aimed at modifying travel behavior through information provision, gamification, and other low-cost strategies. However, behavioral motivation alone is not sufficient when travelers face limited or inconvenient alternatives to personal vehicle use. Infrastructure and service design must complement behavioral strategies by expanding the range of viable travel options.

Emerging mobility services, such as micromobility and ridesourcing, present an opportunity to address these structural limitations. When carefully planned, these modes can reduce first- and last-mile barriers, enhance transit accessibility, and offer flexible alternatives in areas with limited transit services. Yet, their success depends on context-sensitive deployment and on understanding how travelers respond to such interventions. Without thoughtful planning and analysis, these services may remain underutilized or exacerbate existing inefficiencies.

This project lays the groundwork for a more integrated approach to planning and evaluating emerging mobility solutions. Specifically, it developed a series of optimization-based models to address three interrelated challenges: (1) identifying the optimal spatial deployment of emerging mobility services to address gaps in existing transportation supply; (2) improving accessibility through coordinated strategies between public transit and private mobility providers; and (3) encouraging mode shift among travelers who currently rely on personal vehicles by designing targeted, incentive-based multimodal travel strategies. These efforts support the broader objective of enabling more sustainable, efficient, and user-responsive transportation systems.

This chapter presents the modeling approaches developed in Stage 1, describes their structural features and computational implementation, and summarizes preliminary experiments conducted on small-sized grid networks. Detailed optimization models, mathematical proofs, solution algorithms, numerical examples on real-world networks, simulation-based evaluation, and network-scale implementation are planned for Stage 2 (TBD Project #26) report, with the understanding that model refinements or reformulations may be necessary to address real-world constraints and implementation needs.

4.2 Literature Review

Traditional fixed-route public transit systems often fail to mitigate limited access to societal services/activities (e.g., jobs, medical, grocery stores) due to coverage limitations, frequency issues, or inflexible routing structures, which reduce their appeal to personal vehicle users (Cheng & Chen, 2015; Winston, 2013). At the same time, the transportation sector continues to be a major contributor to air pollution and greenhouse gas emissions (Frey, 2018), leading to public health concerns such as respiratory and cardiovascular diseases (Anenberg et al., 2019; Choma et al., 2021). The prevalence of sedentary lifestyles linked to car dependency further compounds these health challenges (J. F. Sallis et al., 2012).

Existing studies explore how emerging mobility options, particularly micromobility and ridesourcing, can bridge spatial and temporal service gaps in traditional transit systems. Micromobility modes like e-scooters and bikes offer flexible first- and last-mile connections (Cici et al., 2014; Shaheen & Cohen, 2020), while ridesourcing services such as Uber and Lyft can extend transit coverage when effectively integrated (Furuhata et al., 2013; Schwieterman et al., 2018). However, many early partnerships between public transit agencies and transportation network companies (TNCs) faced challenges in sustaining ridership and generating meaningful behavior changes (Steiner et al., 2021). Studies suggest that the failure to account for users' perceived utility and individualized preferences contributed to poor adoption of integrated services (Hampshire et al., 2017; Manville et al., 2023).

There is growing recognition that well-designed incentive mechanisms can address barriers to multimodal adoption. Monetary incentives, including cash rewards and discounts, have been explored for altering travel behavior (Albert & Mahalel, 2006b; Wang et al., 2021b). However, such approaches are not generally financially sustainable for long-term implementation. Non-monetary interventions, such as gamified feedback, environmental nudges, and health messaging, are increasingly viewed as promising alternatives (Avineri & Steven, 2013; Baum, 2008). Despite these advances, the application of combined incentive strategies in the context of integrated multimodal transit systems remains limited, particularly in terms of tailoring interventions to individual users (Abou-Zeid & Ben-Akiva, 2012; Bian & Liu, 2019).

Most prior models have focused on either system-level efficiency or user-level disutility, without jointly addressing fairness in accessibility and long-term behavioral response. Existing optimization approaches for deploying shared mobility options (e.g., micromobility hubs) often fail to account for disparities in service availability across zones and the heterogeneous needs of different traveler segments (Charisis et al., 2018; Shen & Quadrifoglio, 2012). There is a lack of integrated modeling frameworks that simultaneously consider spatial accessibility, behavioral adaptation, and incentive-based adoption under a unified methodology.

This chapter contributes to the literature in several ways. First, it addresses the limitations of past transit-TNC partnership studies by focusing on sustained behavior change rather than one-time service use. Second, it develops zone-level optimization models to strategically deploy emerging mobility solutions where they are most needed, thus addressing service supply gaps. Third, it proposes new models that enhance accessibility through partnerships between public transit and private mobility providers, with fairness considerations embedded in the optimization framework. Fourth, it advances incentive-based travel behavior modeling by incorporating both monetary and non-monetary incentives in a unified decision framework designed to shift personal vehicle users toward integrated multimodal systems. These contributions extend existing research by linking service design, partnership mechanisms, and individual behavioral responses within a coherent and actionable framework.

4.3 Summary of Optimization Models to be Validated in Stage 2

To support effective deployment of emerging mobility services and promote sustainable travel behavior, this project developed a series of optimization-based models. These models address different aspects of multimodal planning and behavioral adoption by integrating spatial access constraints, user heterogeneity, and service coordination. The work is organized into three modeling components. The first focuses on determining the optimal spatial placement of emerging mobility services to address supply gaps in the transportation network. The second formulates a framework for improving access through coordination between public transit providers and private mobility operators. The third develops an incentive-based model to encourage personal vehicle users to adopt integrated multimodal travel options. These models provide a foundation for conducting detailed numerical experiments on real-world transportation networks, simulating service outcomes, evaluating user responses, and supporting scenario-based planning in Stage 2.

4.3.1 Zone-level deployment of emerging mobility services

To improve access to essential services in areas underserved by fixed-route transit, this project developed an optimization framework for determining where to deploy emerging mobility options such as micromobility devices, ridesourcing services, or autonomous shuttles. The model is designed to select a subset of geographic zones for deploying these services based on accessibility scores that reflect proximity to several essential destinations (e.g., health centers, schools, grocery stores), population characteristics, and existing transit infrastructure.

The primary objective is to improve access in a balanced and efficient manner. The model incorporates a spatial accessibility score that accounts for travel distance and demand intensity, and it allows for additional considerations such as budget constraints, service capacity limits, and fairness in distribution across zones. The framework can be tailored to different emerging mobility modes by adjusting the service radius, mode types and characteristics, or user eligibility criteria.

To solve the problem, a mixed-integer linear programming formulation was developed and implemented in Python using Pyomo and Gurobi. Model structure and constraints were examined for properties like total unimodularity which supports exact solutions under linear program relaxation. Preliminary tests were conducted on synthetic networks using publicly available sociodemographic and facility data. These tests confirmed that the model responds predictably to changes in deployment budgets and accessibility thresholds, and that it is computationally tractable for medium-scale applications.

Stage 2 will apply this model to real-world networks, including the City of Peachtree Corners, to assess deployment strategies under realistic service constraints and planning objectives. Planned extensions include multi-mode comparisons, sensitivity analyses, and simulation-based validation of deployment outcomes.

4.3.2 Public-private coordination to improve accessibility

In areas with limited transit coverage, enhancing accessibility often depends on coordinated strategies that combine public infrastructure with flexible services offered by private mobility providers. To address this, a model was developed to evaluate how such partnerships can be structured to serve communities more effectively. The focus is on identifying deployment strategies for first- and last-mile (FMLM) services, such as ridesourcing or micromobility, operated by private companies, in coordination with public transit agencies.

The model takes the existing transit network, underserved zones, known demand concentrations, and available mobility service provider capacity as input. It considers a range of planning decisions: which zones should receive subsidized FMLM access, how fleet resources should be distributed, and how much public subsidy is required to meet coverage and performance targets. The objective is to improve accessibility while minimizing total system cost, which includes public subsidies and operational costs borne by providers.

Public agencies are modeled as the planning authority with limited budget and a goal to reduce access gaps. Private providers are represented through cost functions and service constraints, including minimum profitability thresholds or vehicle availability. This structure enables analysis of trade-offs between cost efficiency and spatial coverage, and supports evaluation of deployment schemes that would be infeasible without coordinated action.

The model was formulated as a mixed-integer program and tested on synthetic networks with varying levels of existing transit coverage and population distribution. To improve scalability and maintain interpretability, a compact formulation was developed using aggregated zone-level constraints, with sensitivity analysis performed on fleet size and budget allocation. Results from preliminary runs demonstrated that, compared to uncoordinated deployment (where transit systems and private mobility services operate independently), coordinated strategies significantly increased access coverage, particularly in edge zones where fixed-route expansion would not be cost-effective.

In Stage 2, the model will be validated using real-world data and integrated with survey-informed behavioral assumptions to simulate provider uptake, user adoption, and system-wide impacts under different partnership and pricing arrangements. These efforts will support broader exploration of how public-private coordination can support flexible, cost-effective mobility planning.

4.3.3 Incentive-based multimodal adoption for personal vehicle users

In many regions, particularly those with limited or inconvenient transit access, personal vehicles remain the dominant mode due to their perceived reliability, convenience, and door-to-door capability. To reduce dependence on single-occupancy vehicles, especially in areas classified as transit deserts, it is essential to design strategies that offer viable multimodal alternatives and account for the behavioral barriers that influence travel choices.

This component of the modeling framework focuses on two integrated tasks: first, configuring multimodal trip chains that combine transit with emerging first- and last-mile services; and second, determining the minimum incentives needed to motivate users to adopt these alternatives. The model explicitly accounts for individual user preferences, disutilities, and adoption thresholds, using a two-stage optimization approach.

The first stage minimizes system-level disutility by assigning each user a feasible multimodal trip plan based on available modes, schedules, and physical constraints. The second stage determines the set of incentives—monetary and non-monetary (e.g., reduced transfer wait, health or environmental prompts)—that must be provided to make the alternative preferable to personal vehicle use. The model ensures that all incentives offered are within agency resource limits and tailored to user heterogeneity, with adoption occurring only if the personalized incentive exceeds a minimum threshold of acceptability.

The optimization problem was implemented as a decomposition model using binary variables for non-monetary incentive types and continuous variables for monetary amounts. A baseline assignment was computed without incentives, and the model iteratively adjusted incentives to identify the minimum intervention needed to switch each user while maintaining feasibility at the system level.

Preliminary experiments on small network instances showed that targeted personalized incentive bundling can lead to higher adoption at lower cost compared to flat subsidies. The results also showed diminishing returns for strategies that are not personalized and highlighted the importance of matching incentive type to user profile—some users were more responsive to monetary discounts, while others shifted behavior in response to health-oriented prompts.

Stage 2 will build on these findings by integrating longitudinal survey data that capture real-world behavioral dynamics, enabling simulation of how multimodal adoption unfolds over time under different incentive schemes. The combined modeling and simulation framework will allow evaluation of not only cost and adoption rates but also long-term impacts on travel behavior, access equity, and system performance.

4.4 Conclusions

The models developed in Stage 1 serve as the foundation for applied experimentation and system-level simulation to be conducted in Stage 2. The focus will shift from conceptual and algorithmic development to real-world deployment planning, data integration, and behavioral validation. A major thrust will involve applying the zone-level deployment and coordination models to the City of Peachtree Corners, GA, which has been identified as a testbed due to its varied land use patterns, documented transit gaps, and availability of relevant datasets.

The modeling framework will be populated with actual spatial, sociodemographic, and facility data. The deployment models will be used to simulate placement strategies for emerging mobility services under different objectives (e.g., maximizing accessibility, minimizing disparities, staying within cost constraints).

In parallel, the incentive-based adoption model will be calibrated using behavioral data from a longitudinal field experiment designed and launched as part of Stage 2. Experiment data will inform user-specific thresholds, preferences, and response to different interventions, which will be embedded in the simulation process. A multi-period simulation will be developed to estimate how mode choice evolves over time, how incentives propagate through the system, and how deployment strategies perform under different planning scenarios. These simulations will enable comparisons across policy options and provide practical guidance on designing integrated mobility solutions that are both feasible and responsive to user behavior.

5. Outputs, Outcomes, and Impacts

This chapter summarizes the main products, contributions, and broader implications of the work completed during Stage 1 of the project. The outputs include conference presentations, peer-reviewed publications, survey designs and questionnaires used to assess behavioral responses to interventions, behavioral datasets, and optimization models developed to support the design and evaluation of sustainable mobility strategies. The outcomes describe how these outputs inform understanding of traveler behavior and support integrated planning approaches. The impacts reflect the project's contributions to advancing public health and safety goals, promoting more sustainable travel behavior, and engaging students at multiple academic levels in research and training activities.

5.1 Outputs

5.1.1 Publications and presentations

- Anne, R., Kibria, G., Liu, Y., Asensio, O., & Peeta, S. (2025). "Promoting Sustainable Travel Modes through Gamified Health and Environmental Information." 104th TRB Annual Meeting, Washington, D.C., January 2025. *(Winner of the TRB AEP35 Best Paper Award)*.
- Peeta, S. (2024). Keynote Speaker, "Systems Thinking for Sustainable Urban Mobility," 2nd ACM SIGSPATIAL Workshop on Sustainable Urban Mobility (SuMob 2024), ACM SIGSPATIAL Conference, Atlanta, GA, October 2024.
- Peeta, S. (2024). Distinguished NGTS Seminar Speaker, "Framework for Sustainable Travel Through Smart and Engaged Communities," University of Michigan, MI, April 2024.
- Anne, V. S. R., & Peeta, S. (2024). "Promoting Sustainable Mobility: Behavioral Interventions for Transportation Sustainability and Equity." INFORMS Annual Meeting, Phoenix, AZ, October 2024.
- Anne, V. S. R., & Peeta, S. (2024). "Incentive-Based Travel Behavior Change Mechanisms to Mitigate System-Level Greenhouse Gas Emissions." ASCE International Conference on Transportation and Development, Atlanta, GA, June 2024.
- Kibria, G., & Peeta, S. (2024). "Incentive Designs to Promote Sustainable Travel Behavior through TNC-Transit Partnerships." 17th International Conference on Travel Behavior Research, Vienna, Austria, July 2024.
- Kibria, G., & Peeta, S. (2024). "Leveraging Partnership Between Public Transit and Emerging Private Modes to Enhance Accessibility Equity for Low-Income Populations." INFORMS Annual Meeting, Phoenix, AZ, October 2024.
- Campusano, I., Kibria, G., & Peeta, S. (2024). "Exploration of Transit-TNC Partnerships to Enhance Mobility and Access for Transportation Disadvantaged Groups." ISyE Summer Undergraduate Research Scholars Poster Presentation, Atlanta, GA, August 2024.
- Shirol, S., Kim, Y., Patel, K., Wang, Z., Kibria, G., Anne, V. S. R., & Peeta, S. (2024). "Fostering Sustainable Travel Through Engaged Communities." PIN Summer Internship Closing Ceremony, Morrow, GA, August 2024.

5.1.2 Other products

- Online survey instruments designed to assess the effects of health/environmental messaging and gamification on travel behavior.

- Behavioral datasets from 8,949 respondents used to model user preferences under various interventions.
- Optimization models developed for zone-level emerging mobility deployment, transit-access partnerships, and incentive-based mode shift strategies.
- Preliminary simulation codebases and modeling infrastructure for future integration with real-world networks in Stage 2.

5.2 Outcomes

- Improved understanding of how travelers respond to health and environmental framing and gamification strategies to encourage walking, biking, and transit use.
- Identification of traveler segments most responsive to non-monetary behavioral interventions, supporting the design of cost-effective public campaigns and apps.
- Development of transferable modeling approaches to guide placement of emerging mobility solutions and partnerships between public transit and private mobility providers.
- Enhanced ability to design incentive structures that promote mode shift in car-dependent regions, setting the stage for broader simulation and field validation in Stage 2.

5.3 Impacts

- Demonstrated the potential of low-cost, scalable interventions, such as health-focused messaging and gamified feedback, to influence individual travel decisions and reduce car dependency.
- Provided a methodological foundation for real-world implementation of public-private mobility coordination strategies aimed at improving access in underserved areas.
- Strengthened the transportation research workforce by actively involving:
    - 4 PhD students
    - 1 MS student
    - 21 undergraduate students across disciplines including Civil and Environmental Engineering, Industrial Engineering, Computer Science, and Finance.

6. Conclusion

This report presents the work completed in Stage 1 of the project “Promoting Sustainable Travel within Communities through Behavioral Interventions and Emerging Mobility Solutions”. The project addresses the persistent challenges of heavy reliance on personal vehicles, limited access to sustainable modes, and the resulting health, environmental, and mobility issues.

Stage 1 focused on two complementary research thrusts. First, it designed and evaluated behavioral interventions to motivate travelers to adopt sustainable modes, using strategies such as health- and environment-focused messaging and gamification elements like badges and leaderboards. Large-scale online surveys provided empirical evidence on the effectiveness of these interventions, demonstrating that gain-framed health and environmental information, when delivered through engaging and motivational formats, can significantly increase the likelihood of choosing transit, walking, and biking. The results also highlight that simple information is insufficient unless it is delivered in ways that promote personal relevance, social engagement, and real-time decision-making support.

Second, the project initiated the development of optimization models aimed at enhancing access to sustainable modes through the strategic deployment of emerging mobility services, such as micromobility and ridesourcing. These models incorporated objectives such as improving accessibility, reducing supply gaps, and enabling public-private service coordination. Preliminary numerical experiments demonstrated feasibility and policy relevance, laying the groundwork for subsequent real-world applications.

While Stage 1 concentrated on designing interventions, developing foundational models, and conducting preliminary evaluations, the full-scale testing, calibration with real-world data, and simulation-based validation are reserved for Stage 2. The ongoing Stage 2 efforts will deploy these interventions and models in the City of Peachtree Corners, Georgia, allowing evaluation of behavioral shifts, service impacts, and broader system outcomes in a living laboratory environment.

Overall, Stage 1 establishes a scalable, evidence-based approach for promoting sustainable travel behavior by combining behavioral insights with improved access to viable alternatives. It advances understanding of how informational strategies and emerging mobility solutions can be jointly leveraged to address longstanding transportation challenges and sets the stage for more comprehensive, real-world implementation and validation in Stage 2.

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APPENDIX A: Survey Questionnaire

Part 1 contains a few basic **demographic questions**. **Part 2** consists of your basic **travel-related questions**. **Part 3** shows a **daily travel scenario**. In this scenario, you will be shown a hypothetical daily commute trip and asked to select your preferred travel option from four alternative travel options (car, bus, bike, and walk) followed by a few additional questions. Please answer the questions as realistically as possible. Thank you for your participation!

PART 1: Demographics Questions

What is your sex? (required)

- o Female
- o Male
- o Other (may specify) ____
- o Prefer not to say

What is your age? (required)

____

Are you Hispanic/Latino?(required)

- o Yes
- o No
- o Prefer not to say

Which of the following best describes your race? Select all that apply. (required)

- o White / Caucasian
- o Black / African American
- o Native American / American Indian
- o Asian / Pacific Islander
- o Other (please specify) ____
- o Prefer not to say

What is your current employment status? (required)

- Employed full-time
- Employed part-time
- Self-employed
- Unemployed (currently looking for work)
- Unemployed (not currently looking for work)
- Student
- Retired

What is the highest degree or level of school you have completed? (required)

- Less than a high school diploma
- High school diploma or equivalent
- Bachelor's degree (BA, BS, etc.)
- Master's degree (MA, MS, etc.)
- Doctorate (PhD, EdD, MD, etc.)
- Other (please specify) ____

How many people live in your household?

- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9 or more

To get a representative sample in this study, we require an estimate of your gross (before tax) annual **household income**. Please select the option that best fits your household. (required)

- Less than $10,000
- $10,000 - $15,999
- $16,000 - $19,999
- $20,000 - $29,999
- $30,000 - $39,999
- $40,000 - $49,999
- $50,000 - $59,999
- $60,000 - $69,999
- $70,000 - $79,999
- $80,000 - $89,999
- $90,000 - $99,999
- $100,000 - $149,999
- More than $149,999

Please indicate the type of home you currently live in: (required)

- Single-family attached house
- Building with 2 or more apartments or condos
- Mobile home or trailer
- Dorm room, fraternity or sorority
- Other (please specify) ______________________________

Which type of urban setting do you currently reside in? (required)

- Urban (with limited access to transit)
- Urban (with adequate transit access)
- Suburban
- Rural

PART 2: Travel Behavior Questions

What travel modes do you typically use during your daily commute? Select all modes that apply. (required)

- o Walking
- o Bicycle/scooter (privately owned)
- o Bicycle/scooter (shared transportation services)
- o Automobile (privately owned; as driver)
- o Automobile (privately owned; as passenger)
- o Automobile (shared transportation services)
- o Transit - bus
- o Transit - train
- o Taxi
- o Transportation network companies (Uber, Lyft, etc.)
- o Autonomous shuttles
- o Other travel mode (please specify)

  ____

What is the typical travel time of your daily commute using the travel mode(s) you indicated (one way)? (required)

- o Less than 15 minutes
- o 16-30 minutes
- o 31-45 minutes
- o 46-60 minutes
- o 1-1.5 hours
- o 1.5-2 hours
- o More than 2 hours

What travel modes do you typically use during your daily non-commute? Select all modes that apply. (required)

- o Walking
- o Bicycle/scooter (privately owned)
- o Bicycle/scooter (shared transportation services)
- o Automobile (privately owned; as driver)
- o Automobile (privately owned; as passenger)
- o Automobile (shared transportation services)
- o Transit - bus
- o Transit - train
- o Taxi
- o Transportation network companies (Uber, Lyft, etc.)
- o Autonomous shuttles
- o Other travel mode (please specify) ______________________________

Do you currently have any underlying health conditions? Please select all that apply. (required)

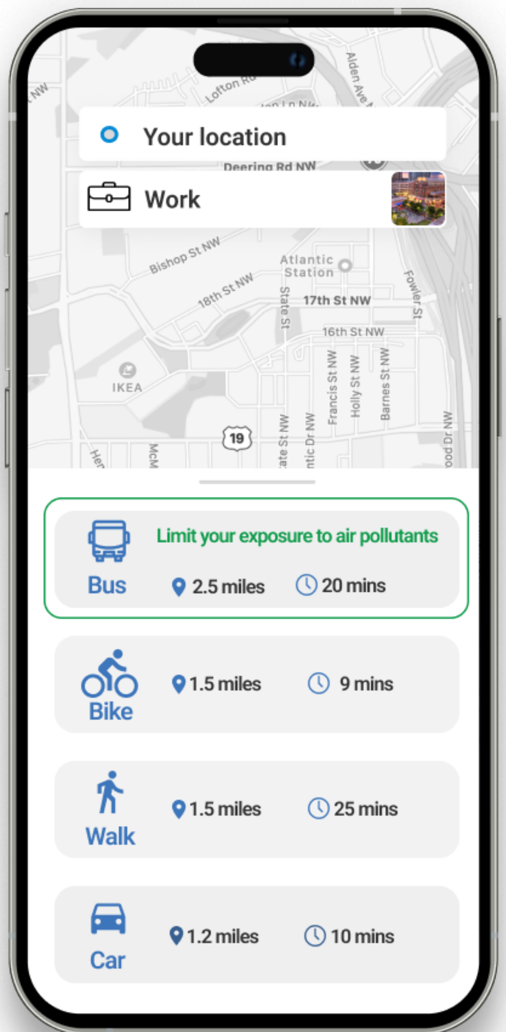
- o No underlying health conditions
- o Diabetes
- o Hypertension (High Blood Pressure)
- o Cardiovascular Disease
- o Respiratory Conditions (e.g., Asthma, Chronic Obstructive Pulmonary Disease - COPD)
- o Other
- o Prefer not to answer

Please rate the extent to which you agree/disagree with the following statements: (required)

	Strongly disagree	Disagree	Somewhat disgaree	Neutral	Somewhat agree	Agree	Strongly agree
I am open to trying out alternative transportation modes (other than my preferred modes) for my daily commute trips	○	○	○	○	○	○	○
I am open to trying out alternative transportation modes (other than my preferred modes) for my daily non-commute trips	○	○	○	○	○	○	○
I am concerned about my carbon footprint	○	○	○	○	○	○	○
If I knew how to better reduce my carbon footprint, I would take action	○	○	○	○	○	○	○
I maintain an active lifestyle	○	○	○	○	○	○	○
I am health conscious	○	○	○	○	○	○	○
If I knew how to better contribute to improve air quality, I would take action	○	○	○	○	○	○	○
When making decisions, I consider the opinions or approval of others around me	○	○	○	○	○	○	○

An Example of Informational Messaging

Instructions: Suppose you are on your way to work and you use a navigation app (such as Google Maps, Apple Maps, Waze, etc.). You have four alternative options as shown in the screen below. Assume all four options are available to you. Please choose the option you prefer the most.



Please rate the extent to which you agree/disagree with the following statements: (required)

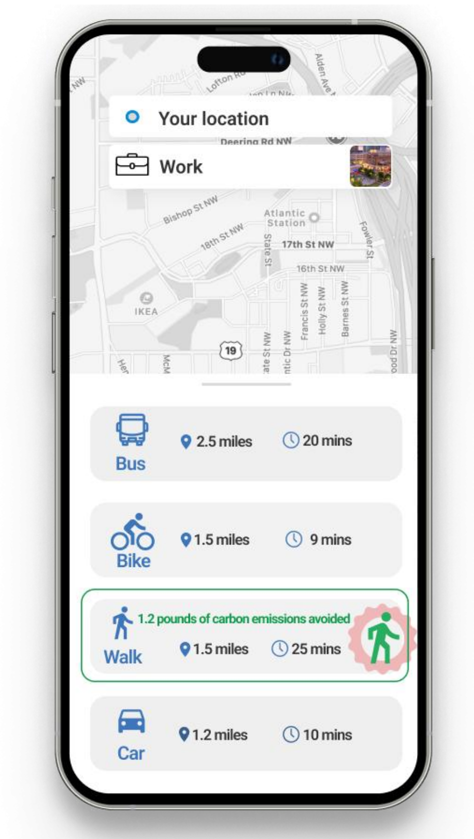
	Strongly disagree	Disagree	Somewhat disagree	Neutral	Somewhat agree	Agree	Strongly agree
I understand the message	○	○	○	○	○	○	○
I believe the information in the message	○	○	○	○	○	○	○
Taking the bus is a viable option for me	○	○	○	○	○	○	○
The information in the message is relevant to me	○	○	○	○	○	○	○
I would change my behavior based on the message	○	○	○	○	○	○	○

Would you consider taking a bus under the above scenario if the trip purpose was changed from commute to the following? Please select all the options for which your answer is "yes". (required)

- ○ Shopping: Trips to retail stores, supermarkets, or malls for purchasing goods and products.
- ○ Entertainment: Visits to theaters, cinemas, concerts, sports events, amusement parks, or other recreational activities.
- ○ Social: Meeting friends or family, attending social events, parties, or gatherings.
- ○ Medical/Healthcare: Trips for doctor's appointments, medical consultations, or visits to healthcare facilities.
- ○ Errands: Running miscellaneous errands, such as banking, post office visits, or other personal tasks.
- ○ Fitness: Trips to gyms, fitness centers, or outdoor exercise locations.
- ○ I would not take the bus under any scenario

An Example of Gamification Elements (Badges)

Instructions: Suppose you are on your way to work, and you use a navigation app (such as Google Maps, Apple Maps, Waze, etc.). You have four alternative options as shown in the screen below. Assume all four options are available to you. **Moreover, suppose badges (digital awards) are awarded based on the amount of emissions avoided.** In this scenario, you can **earn the next badge** by walking in this trip. Please choose the option you prefer the most. (required)



Please rate the extent to which you agree/disagree with the following statements: (required)

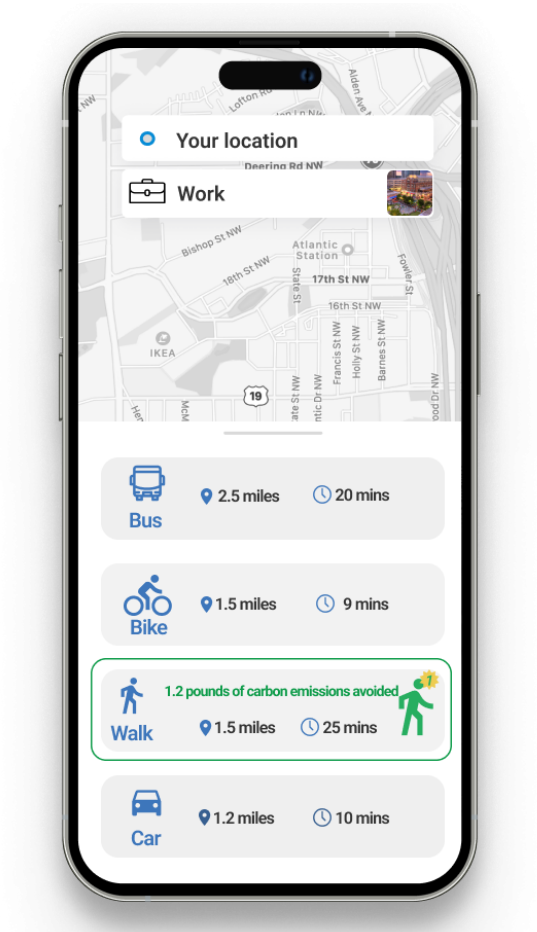
	Strongly disagree	Disagree	Somewhat disagree	Neutral	Somewhat agree	Agree	Strongly agree
I understand the requirements to get the badge	○	○	○	○	○	○	○
I believe in the information in the message	○	○	○	○	○	○	○
Walking is a viable option for me	○	○	○	○	○	○	○
This badge is relevant to me	○	○	○	○	○	○	○
I would change my travel decision to get the badge	○	○	○	○	○	○	○

Would you consider walking under the above scenario if the trip purpose was changed from commute to the following? Please select all the options for which your answer is "yes". (required)

- ○ Shopping: Trips to retail stores, supermarkets, or malls for purchasing goods and products.
- ○ Entertainment: Visits to theaters, cinemas, concerts, sports events, amusement parks, or other recreational activities.
- ○ Social: Meeting friends or family, attending social events, parties, or gatherings.
- ○ Medical/Healthcare: Trips for doctor's appointments, medical consultations, or visits to healthcare facilities.
- ○ Errands: Running miscellaneous errands, such as banking, post office visits, or other personal tasks.
- ○ Fitness: Trips to gyms, fitness centers, or outdoor exercise locations.
- ○ I would not walk under any scenario

An Example of Gamification Elements (Leaderboard)

Instructions: Suppose you are on your way to work, and you use a navigation app (such as Google Maps, Apple Maps, Waze, etc.). You have four alternative options as shown in the screen below. Assume all four options are available to you. Moreover, suppose **a leaderboard keeps track of travel behavior in your community and ranks them based on the amount of emissions avoided.** In this scenario, you can **move up the leaderboard** by walking in this trip. Please choose the option you prefer the most. (required)



Please rate the extent to which you agree/disagree with the following statements: (required)

	Strongly disagree	Disagree	Somewhat disagree	Neutral	Somewhat agree	Agree	Strongly agree
I understand the requirements to move up the leaderboard	○	○	○	○	○	○	○
I believe in the information in the message	○	○	○	○	○	○	○
Walking is a viable option for me	○	○	○	○	○	○	○
This leaderboard is relevant to me	○	○	○	○	○	○	○
I would change my travel decision to move up the leaderboard	○	○	○	○	○	○	○

Would you consider walking under the above scenario if the trip purpose was changed from commute to the following? Please select all the options for which your answer is "yes". (required)

- o Shopping: Trips to retail stores, supermarkets, or malls for purchasing goods and products.
- o Entertainment: Visits to theaters, cinemas, concerts, sports events, amusement parks, or other recreational activities.
- o Social: Meeting friends or family, attending social events, parties, or gatherings.
- o Medical/Healthcare: Trips for doctor's appointments, medical consultations, or visits to healthcare facilities.
- o Errands: Running miscellaneous errands, such as banking, post office visits, or other personal tasks.
- o Fitness: Trips to gyms, fitness centers, or outdoor exercise locations.
- o I would not walk under any scenario