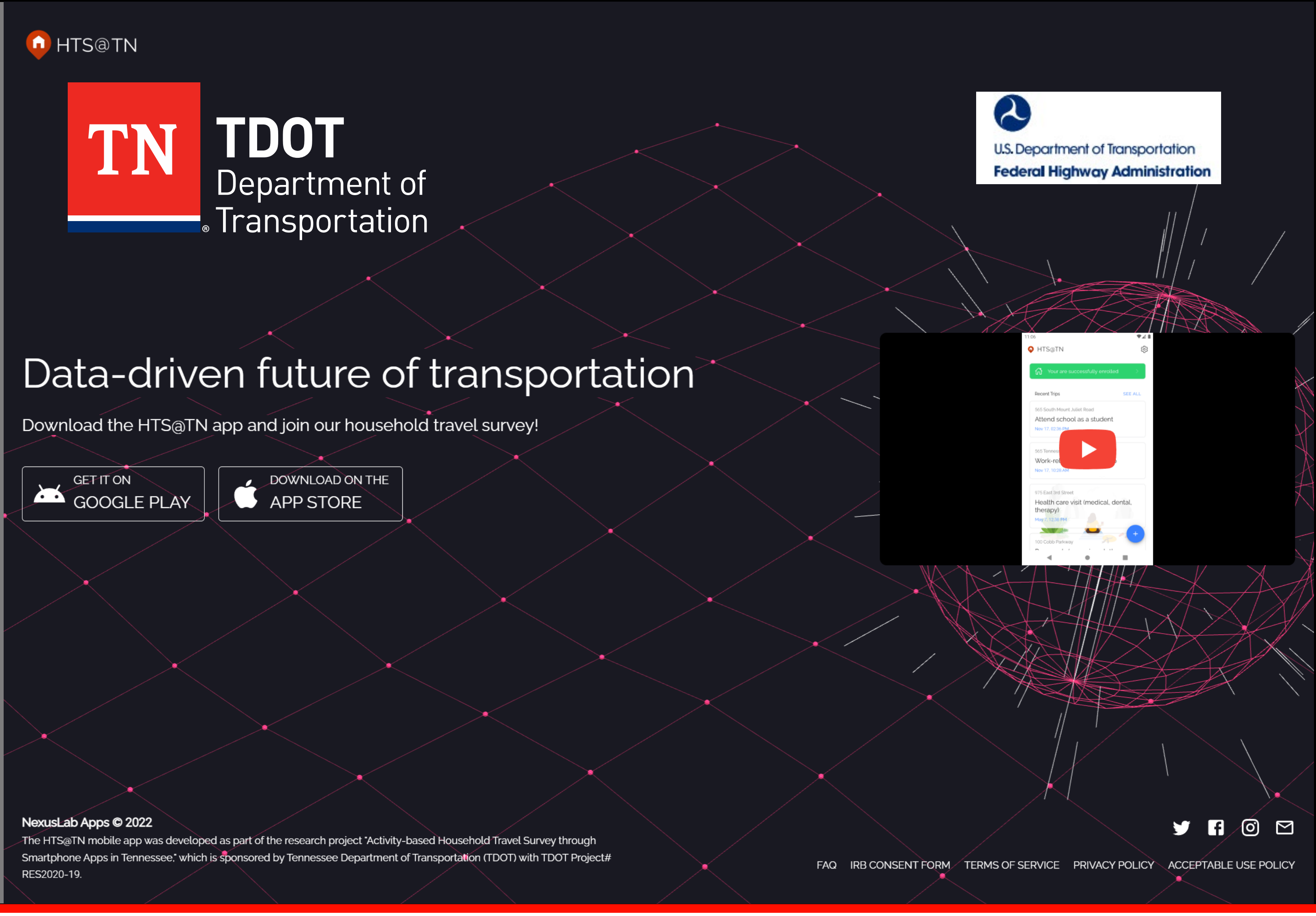

Activity-Based Household Travel Survey through Smartphone Apps in Tennessee

Research Final Report from The University of Tennessee at Chattanooga | Mengjun Xie, Dalei Wu, and Li Yang | October 31, 2022 Sponsored by Tennessee Department of Transportation Long Range Planning

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16. Abstract

Activity-based household travel surveys (HTS) are one of primary data sources for many research fields at Tennessee Department of Transportation (TDOT). Traditional HTS methods are often costly, time-consuming, less scalable, and difficult to achieve high quality and accuracy. Recent years have witnessed a fast-growing interest in conducting HTS through smartphone apps to address survey issues and improve quality of collected survey data. A research project on activity based HTS through smartphone apps for both Android and iOS has been perfomed. The overarching goal of this research project is to develop an effective, economical, scalable HTS solution for TDOT. To achieve this goal, with the guidance and support from TDOT, the research team has 1) developed a smartphone-based effective, scalable, and secure application for household travel surveys that can span from days to months, 2) integrated fine-grained location information in submitted travel data by leveraging smartphone built-in sensor technologies, and 3) validated the developed HTS application by running a pilot HTS with the application. The pilot survey lasted three months. During the survey study, over 800 people downloaded the mobile apps and registered an account. Over 200 participants have been given a reward for completing the survey. Over 1,800 trips were submitted by those rewarded participants. This research project brings the following benefits to TDOT: 1) A tested, comprehensive smartphone app based HTS solution, 2) Important findings about smartphone app based HTS gained from running the pilot survey study, and 3) An anonymized survey dataset for research exploration obtained from the pilot survey study. A number of key findings as well as recommendations are also generated from this research project and they will help TDOT conduct HTS more effectively and generate more research results in the future.

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Executive Summary

Activity-based household travel surveys (HTS) are one of primary sources that provide detailed information of people's travel activities. HTS data is foundational for many research fields including travel demand modeling and integrated transportation and land-use planning. Traditional methods for conducting HTS include physical mail, phone call, and GIS devices, which are often costly, time-consuming, less scalable, and difficult to achieve high quality and accuracy. With rapid advancement and market penetration of smartphone technologies, recent years have witnessed a fast-growing interest in conducting HTS through smartphone apps, which has a great potential to address many issues faced by traditional survey methods and to improve the overall quality of collected survey data.

The research team has performed a research project on activity based HTS through smartphone apps for both Android and iOS. The overarching goal of this research project is to develop an effective, economical, scalable HTS solution for TDOT. To achieve this goal, with the guidance and support from TDOT, the research team has accomplished the following three research objectives:

1) *Develop a smartphone-based effective, scalable, and secure application for household travel surveys that may span from days to months.* In this project, we have developed and delivered a smartphone-based application, HTS@TN, for household travel surveys. The HTS@TN application consists of an application server, a web app for data view and survey administration, and two mobile apps (one for Android and the other for iOS) for logging trips. All the communications between an HTS@TN mobile app and its server are securely transferred via standard network security protocols. The pilot survey study and app user feedback have demonstrated that the HTS@TN application is effective and scalable and can run for months.
2) *Integrate fine-grained location information in submitted travel data by leveraging smartphone built-in sensor technologies such as GPS sensors.* The HTS@TN mobile apps provide a convenient automatic tracking function through which users can submit travel information integrated with fine-grained geolocation data. The automatic tracking function has been used by multiple survey participants in the pilot study and over 360 trips submitted contain GPS data.
3) *Validate the developed HTS application by running a pilot HTS with the application.* The research team has validated the HTS@TN application by using it to run a pilot HTS for months. Over 200 survey participants from Tennessee or from a neighboring state of Tennessee completed the survey and submitted over 1,800 trips through the HTS@TN mobile apps.

The HTS@TN application is based on the classic client-server model. The mobile apps are responsible for providing a user-friendly interface for app users to participate in an HTS and record their trips. The web app is mainly for survey administration. Those apps communicate with the server through a REST (Representational State Transfer) application programming interface (API) designed for the application. The HTS@TN server provides a list of REST API endpoints to the HTS@TN mobile and web apps so that they can easily retrieve and upload household recruitment survey answers, trip details, user feedback, and other user-generated data. All data is persistently stored in the backend database. Frequently requested data are also temporarily stored in the cache storage to improve system performance and user experience. All communications between the HTS@TN apps and the server are secured by HTTPS. In addition, the application also incorporates third-party services such as Google Maps API and Gmail services to provide functions needed.

A pilot HTS study was conducted in this research project to test the efficacy of the developed HTS@TN application. The process of performing the pilot HTS study consists of the following steps: 1) determining the survey scope and duration, 2) obtaining all necessary approvals for the survey from both TDOT and UTC including UTC Institutional Review Board (IRB) and UTC Finance and Administration, 3) deploying the HTS@TN application in a production environment at UTC, and 4) launching the survey, recruiting survey participants, checking survey progress, and performing necessary processing and related activities during the survey period.

The pilot HTS study was designed as a 2-stage survey in which UTC students/employees were the primary target population in the first stage while Tennessee residents in general as well as UTC students and employees were targeted in the second stage. The 2-stage design was aimed to provide the HTS@TN application with a relatively small and uniform survey population to start with and to evaluate its performance when the user base became much larger and more diverse. To account for travels across the state border, not only Tennessee residents but also residents in one of the Tennessee neighboring states were allowed to participate in the pilot survey study. The pilot survey began on April 12 and ended on July 11. The second stage started in the middle of May. All survey participants were required to use the mobile app for seven consecutive days upon their recruitment survey was approved, no matter in which stage.

Some basic statistics from the pilot survey study are as follows:

- Registered users: 838
- Submitted trips: 3,488
- Submitted households: 735
- Submitted household members: 1,093
- Submitted vehicles: 739
- Approved recruitment survey submissions: 505
- Declined recruitment survey submissions: 406
- Rewarded participants: 223
- Households submitted by rewarded participants: 223
- Members submitted by rewarded participants: 369
- Vehicles submitted by rewarded participants: 232
- Trips submitted by rewarded participants: 1,864

More detailed information about the recruitment survey data, trip data, app feedback data, service performance data, and social media advertisement data can be found in the report.

The research results and findings from this project bring the following benefits to TDOT:

1) *A tested, comprehensive smartphone app based HTS solution.* With the delivered source code, database design, and detailed software deployment guide for the HTS@TN application, TDOT will be able to build all the application components including the server, web app, and mobile apps for Android and iOS, deploy them, and use the HTS@TN application to conduct a household travel survey of their choice.

2) *Important findings about smartphone app based HTS gained from running the pilot survey study.* These findings are listed in the “Key Findings” section below.
3) *An anonymized survey dataset for research exploration obtained from the pilot survey study.* The collected survey data was exported into files from the production database in the CSV format and anonymized for privacy purpose. Those CSV files can be easily imported into mainstream database management systems or loaded into a program for data analysis. The fine-grained data records will allow for new methods to be developed to gain in-depth, multi-facet understanding of people’s travel behavior.

Key Findings

- The pilot survey study demonstrates that the smartphone app based HTS is an effective and scalable approach and the HTS@TN application can run for months with satisfying performance, usability, and reliability.
- The pilot survey study also demonstrates that fine-grained location information of a trip can be effectively and efficiently collected by the HTS@TN mobile apps.
- Social media can play a very important role in recruiting survey participants. If the strategy for social media advertisement is appropriate, recruitment of survey participants can be highly cost-effective.
- It is crucial to put fraud detection/prevention mechanisms in place for achieving high data quality and preventing resource abuse when performing a smartphone app-based household travel survey.

Key Recommendations

- *Automation of HTS Tasks and Fraud Detection/Prevention.* In the pilot survey study, recruitment surveys and trips submitted were manually examined, which is time consuming. Automating such HTS tasks would substantially improve the work efficiency. However, the automation of those tasks needs to be carefully designed and applied, due to the challenge of fraud detection/prevention in HTS. Fake accounts and repeated, forged submissions by programs as well as human users are well-known problems to online applications including mobile apps. Automation of HTS tasks such as trip and recruitment validation should be pursued but it should be carefully designed with fraud detection/prevention built in from the beginning, extensively tested in real-world scenarios, and incrementally deployed with closely monitoring.
- *Survey Customization.* Changes to household travel survey, e.g., changes of recruitment survey questions or trip log questions, are bound to happen. The HTS@TN application has already taken this into consideration in its design and implementation. In the future, more customization on survey administration and survey features may be needed for different HTS performed by TDOT. When needs for survey customization cannot be fully accommodated by the current version of HTS@TN, an incremental approach to expanding application support for survey customization is recommended. Gradual incorporation of new features for survey customization is preferred to a radical change, which, however, should not be interpreted as always simply patching the application.
- *Software Updating.* Today’s software systems, such as software frameworks, libraries, and mobile apps, are rapidly evolving and frequently upgraded to new versions, which often

makes their older versions obsolete and incompatible. Applications that built upon older versions of software frameworks and libraries might not work well or not function at all with their new versions. Because of this, it is recommended to check code dependencies of the HTS@TN mobile apps (Android and iOS) and web app periodically with newer versions of platforms and libraries.

- *Data Visualization and Analytics.* The HTS@TN web app provides a dashboard through which survey administrators can view submitted data. However, no data analytics functionality is provided in the current version. Given their importance to research at TDOT, data analytic functions and features are recommended for future extension of the HTS@TN application. Data visualization and analytics with easy-to-use Web interfaces will help TDOT researchers easily access and interpret collected data through a Web browser and discover interesting patterns and insights from the data. Different visualization approaches are recommended to be included to facilitate data exploration. A variety of common statistics analyses and machine learning methods should also be included.

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Glossary of Key Terms and Acronyms

API	Application Programming Interface
App	Application
HTS	Household Travel Surveys
HTTP	Hypertext Transfer Protocol
HTTPS	Hypertext Transfer Protocol Secure
IRB	Institutional Review Board
JSON	JavaScript Object Notation
REST	Representational State Transfer
SDK	Software Development Kit
VPN	Virtual Private Network
UI	User Interface
UML	Unified Modeling Language

Chapter 1 Introduction

1.1 Research Objectives

Activity-based household travel surveys (HTS) are one of primary sources that provide detailed information of people's travel activities. HTS data is foundational for many research fields including travel demand modeling, transportation mode choice analysis, and integrated transportation and land-use planning. Traditional methods for conducting HTS include physical mail, phone call, and GIS devices, which are often costly, time-consuming, labor intensive, less scalable, and difficult to achieve high quality and accuracy. With rapid advancement and market penetration of smartphone technologies, recent years have witnessed a fast-growing interest in conducting HTS through smartphone apps, which has a great potential to address many issues faced by traditional survey methods and to improve the overall quality of collected survey data.

Echoing this research trend, we have performed a research project on activity based HTS through smartphone apps for both Android and iOS. The overarching goal of this research project was to develop an effective, economical, scalable HTS solution for TDOT. This project was aimed to achieve the following research objectives:

1. *Develop a smartphone-based effective, scalable, and secure application for household travel surveys that may span from days to months.* Although a few app-based HTS studies have been reported, the travel surveys conducted in those studies were arranged in one or multiple designated days; in other words, the entire timespans for all collected survey data in those studies are relatively short (in days). To our best knowledge, no app-based HTS has been implemented over months. However, long-lasting HTS would provide a very different dataset for travel and transportation research, which is helpful for finding solutions and answers from a new perspective and a wider horizon. In this project, we have implemented a smartphone-based application, HTS@TN, which consists of an application server, a web app for data view and survey administration, and mobile apps for Android and iOS.
2. *Integrate fine-grained location information in submitted travel data by leveraging smartphone built-in sensor technologies such as GPS sensors.* Previous app-based HTS studies suggest that smartphone apps improve data quality compared to traditional HTS methods. Trips automatically recorded by the developed HTS@TN mobile apps provide fine-grained data records (e.g., data points generated at second level) and rich data features (e.g., timestamp and GPS location), which can accelerate data-driven research on transportation and land-use modeling and planning at different timescales.
3. *Validate the developed HTS application by running a pilot HTS with the application.* After we developed the HTS@TN application and received all the necessary approvals, we ran a pilot HTS using HTS@TN, which spanned three months and required survey participants to use HTS@TN mobile apps to log their trips for seven consecutive days. The pilot survey initially targeted people at the University of Tennessee at Chattanooga (UTC) and then was expanded to adult residents living in Tennessee or one of its neighboring states in the middle of the HTS. Over 500 people were accepted for participation in the pilot survey and close to 3,500 trips were submitted from all survey participants over the entire survey

period. The HTS@TN application ran well during the pilot study and received overall positive feedback from the survey participants.

1.2 Scope of Work

This research project includes the following tasks:

1. Conduct comprehensive literature review on household travel survey and smartphone app-based survey.
2. Conduct analysis of requirements and system design for the HTS@TN server, mobile apps, web app, and associated backend database.
3. Develop survey instruments and related policies for the pilot survey study.
4. Obtain all necessary approvals for the pilot survey study.
5. Develop, test, and optimize the HTS@TN application.
6. Develop survey participant recruitment strategies and conduct recruitment activities.
7. Deploy, monitor, and maintain the HTS@TN application during the pilot study.
8. Collect and process survey data from participants.
9. Submit quarterly reports and provide final project deliverables at the end.

1.3 Report Organization

The remainder of this project report is structured as follows. Chapter 2 provides a comprehensive literature review on household travel survey technologies, smartphone app-based HTS approaches, and comparisons between smartphone app-based HTS approaches and traditional approaches. Chapter 3 describes the research methodology, in particular, the design of the HTS@TN application and how the pilot HTS study was conducted. Chapter 4 presents the outcome of our software development effort and the results and findings from the pilot study. Chapter 5 concludes this report with final thoughts and recommendations. The rest of the report includes the references and a set of appendices that complement the main content.

Chapter 2 Literature Review

Studies on house travel survey (HTS) have a long history. In the past ten years, with the advancement of smartphone and sensing technologies, smartphone based HTS projects have become increasingly popular. In this project, we conducted a comprehensive literature review on smartphone-based HTS studies and summarize those studies relevant to our project in this report.

We started with the nine articles referenced in our project proposal. From those papers, we searched their referenced papers and the papers referencing them and obtained a collection of papers related to the initial set. We then reviewed the papers in the collection and newly published papers and identified a total of more than 30 papers that are closely related to our project. Different papers were focused on different topics of HTS. Those topics mainly include: i) technology trends of HTS, ii) real-world smartphone based HTS systems with field testing/evaluation, iii) comparison between smartphone based HTS and other HTS methods, iv) GPS-enabled HTS, v) machine learning for smartphone based HTS data analysis and visualization, and vi) other aspects. Next, we will present the review of those papers in different topic categories.

2.1 Technology Trends of HTS

The technology trends and future directions of HTS have been studied in some works with GPS and smartphones mentioned as promising technologies for HTS to improve data quality, decrease respondents' burden, and improve survey participation [1][3]. In paper [1] "**Household Travel Surveys: Where Are We Going?",** Stopher and Greaves studied the evolution of household travel survey from late 1970s to late 2000s. Before 1970s, household travel surveys were done through face-to-face interviews, during which the interviewee was asked to recall the trips in the previous day. Then, the diary survey was first introduced in the late 1970s. People were asked to report the origins and destinations of their trips during each day using a booklet. This form of survey was improved over time to increase its reporting capability and reduce respondent burden. And it was still in use during early 2000s. However, the cost is high for face-to-face or telephone interviews and response collection and non-response rates keep rising.

The authors pointed out the promises for HTS data collection had emerged. They believed that surveys based on global positioning system (GPS) would become feasible and beneficial as the GPS sensor became smaller with higher accuracy. The GPS sensor can be embedded into wearable devices and mobile phones and can provide additional data along with travel time, movement speed, and user location. The advantage of using GPS lies in its capability of collecting data over many days and report precise geographical data of the travel. The authors also suggested using panel surveys where the respondents are recruited and refreshed along the survey process. With the right incentive, the panel survey may overcome some of the issues in traditional diary surveys such as growing non-response rate. In addition, the authors discussed the concept of continuous measurement and data fusion and their effects on cutting down the cost of HTS.

In paper [3] **"The Future Direction of Household Travel Surveys Methods in Australia,"** Shen *et al.* conducted a review study on the recent HTS methodologies implemented in Australia and worldwide. Compared to face-to-face and telephone interviews, web-based surveys, and CATI (Computer Assisted Telephone Interviewing) are becoming increasingly popular in HTS. From early 2000s, GPS and smartphone based household travel surveys have been tested in several countries. The respondents were asked to carry a GPS/smartphone device, when they were travelling, which would collect travel data for several days. In addition, the respondents were also required to fill out online forms to provide their demographic information. Meanwhile, most household travel surveys in Australia were still based on face-to-face interviews and respondents' travel diaries.

The authors suggested two directions for improving HTS in Australia. One direction is to increase the use of computer-assisted survey methods, which will decrease respondents' burden. The other is to use passive collection methods by introducing new technologies such as GPS and smartphone. Using GPS devices can improve data quality. Travel modes and trip purpose can also be inferred from collected GPS data. One concern regarding GPS is battery consumption and some studies adopted network-based location services instead of GPS. The authors also suggested introducing additional data sources such as smart card and bank transaction information into HTS. Combined with big data analysis, these data sources can be used to supplement traditional travel data for data validation. Finally, the authors presented a case study of using the Opal card data to validate the Sydney HTS data in the Sydney CBD area.

2.2 Real-world Smartphone based HTS Systems with Field Testing/Evaluation

A number of smartphones based HTS systems with real-world app design and field evaluation have been reported [7][11][12][23][24][25][28][30][31][33]. In paper [7] **"Design and Implementation of a Smartphone-based Travel Survey,"** Safi *et al.* presented a smartphone-based individual travel survey system that was aimed to address a number of HTS challenges including participant involvement, battery drain, interruption of participants' daily activity, and data privacy. The system was developed using a prompted-recall data collection approach, where travel activities are logged passively using an app named the advanced travel logging application for smartphones (ATLAS II) and the participant is asked to label these activities via the app.

ATLAS II runs on iOS devices and can automatically start and stop trip recordings. It supports full day tracking through advanced battery optimization. ATLAS II uses GSM signal changes to detect participant's movements and then uses GPS sensor to start/stop recording a trip. Recorded trips are uploaded at participant's request. Therefore, there is no real-time data transmission when recording a trip. Participants can view their travel activities of present day on a map and start/stop recording a new trip. They can also review all previous recorded trips and manage user profile with ATLAS II. The app includes a help section with tutorials and frequently asked questions and their answers.

The survey system was evaluated through a national HTS of New Zealand with 77 participants over 2 months. Each participant must report data for 3 weekdays. The survey results show that the participants felt the data collection procedure interesting and 71% of them continued their participation beyond the request period. The results also demonstrated the intuitive design of the app as 94% of the participants completed the survey without any support.

In paper [11] "**Supporting Large-Scale Travel Surveys with Smartphones - A Practical Approach,"** Nitsche *et al.* discussed the general requirements for travel surveys and proposed a smartphone-based approach to collecting HTS data while using machine learning to reconstruct individual trips and detect travel modes. For a large-scale travel survey, the authors discuss several requirements that need to be met and the constraints and limitations of using smartphones for such a survey. These requirements include: 1) The chosen sample of a population must be representative in terms of spatial, temporal, socio-demographic, transport modes, and trip purpose. The usage of smartphone may pose a bias towards younger people or people with a preference for phone. 2) Collected data must be compatible with standardized data analyses and post-processing. 3) Collected data needs to be able to accurately reconstruct the original trip. A smartphone-based survey can cover required information and reduce the chance of underreporting trips. 4) The user interface of smartphone survey app must be simple and intuitive to prevent distracting participants or impacting phone performance. 5) Data privacy must be considered when designing and conducting a smartphone-based travel survey.

The authors then presented an implementation of smartphone-based travel survey app, which used GPS, acceleration, and magnetic field sensors for logging position, speed, bearing, and accuracy of the GPS tracking points as well as acceleration and magnetic field. Network-based and cellular-based positioning methods were also used when GPS signal was lost. Data was collected from 15 volunteers over a period of 2 months. The participants could annotate their transport modes for each trip and correct annotations in post-processing. In post-processing, GPS tracks are preprocessed with a Kalman filter and sliced into multiple time windows. For each time window, features are extracted and fed into a Discrete Hidden Markov Model (DHMM) and a most likely transport mode is selected for that time window. The evaluation results show that the accuracy of classifications ranges from 65% (train, subway) to 95% (walk).

In paper [12] **"Smartphone based Travel Diary Collection: Experiences from a Field Trial in Stockholm,"** to examine whether a smartphone-based HTS can be used to replace or supplement traditional travel diary, Allström *et al.* developed MEILI, an open-source system that uses a smartphone app to capture movement of an HTS participant and a Web application to annotate recorded travel activities. The system also employs a number of algorithms to infer travel semantics such as travel mode and purpose to reduce participant burden.

The authors compared MEILI to traditional Web-based travel diary in a field trial in 2015. A total of 495 people signed up for the trial. 2,142 trips were collected and annotated by 171 participants. During the day chosen for HTS methods comparison, the participants were first asked to use MEILI to collect travel data, but they were not shown the collected data. They were then required to fill out the Web-based travel diary the next day and given access to review and annotate the trips recorded by MEILI after they submitted the travel diary. The follow-up survey results indicate that MEILI smartphone app functioned as expected and battery consumption did not appear to be a problem for most of the participants. The main issue reported by the participants was in the annotation process in the website component of MEILI. Additionally, MEILI was able to accurately match 53.2% trips collected by the app with the web-based travel diary. It also inferred stop locations, trip-leg constructs, and complete trip chain with relatively high accuracy. The trip purpose inference has lower accuracy due to the complexity of human travel activity.

In paper [23] **"Harnessing Smartphone Sensors for Tracking Location to Support Travel Data Collection,"** Ellison *et al.* reported development of a smartphone app that balances the need for quality data with battery life and its use in a seven-day travel survey in Sydney, Australia. The use of Wi-Fi/mobile network location instead of GPS and a variable polling rate reduced battery drain to the point where the smartphone could generally be used all day for normal use without being charged. The stop-detection algorithm provided an accurate and robust method for identifying areas in which a stop has occurred.

The authors compared the performance of the smartphone app with that of a widely used GPS device, using data collected from the same trips during the seven-day travel survey. The results indicate that the smartphone app provides data of equal, and in many cases, better quality than the GPS device in urban areas. This is particularly true in heavily built-up areas and on short trips where GPS struggles to provide accurate data. However, the quality of smartphone data is largely similar to the quality of the GPS data collected by each person in that those with poor quality GPS data also tend to have poor quality smartphone data.

In paper [24] **"Future Mobility Survey,"** The Future Mobility Survey (FMS) was a smartphone-based prompted recall travel survey deployed in Singapore. Cottrill *et al.* presented the considerations on the survey's development including smartphone apps for iPhone and Android platforms, online activity diary and user interface, and background intelligence for processing collected data into activity locations and travel traces.

The FMS collected user input in four stages: 1) Registration in which participants provide basic households information such as age range, gender, education level, etc. 2) Presurvey in which participants provide more detailed information including socioeconomic information and vehicle ownership. 3) Activity diary in which participants visit the FMS website to validate activity and mode information recorded and detected from use of the FMS app. 4) Exit survey where participants provide feedback on the survey experiment.

Although the pilot implementation had not resulted in a statistically significant sample, the authors found that it still provided valuable insights into user needs concerning the interface as well as training data for the background intelligence for stop and mode detection. A need was found to ensure a clear survey workflow and simple user interaction to maintain participation rates. The study demonstrated the possibilities of smartphone-based travel surveys and the effort needed for successful deployment. The authors also found that the participation process should be simple, with the approach striking an appropriate balance between data collection and battery life and should ensure that smartphone users do not feel overwhelmed by the requirements for participation.

In paper [25] **"Future Mobility Sensing: An Intelligent Mobility Data Collection and Visualization Platform,"** You *et al.* presented FMS, which was designed and implemented as a multi-source data collection and visualization solution with two key components, FMS Data Collection Platform and FMS Data Fusion and Visualization Platform. They summarized various applications of the FMS system and reported an exploratory analysis of the data from a commercial vehicle parking study in Singapore. The generic FMS system can be used to support various passenger travel and freight movement surveys.

FMS Data Collection Platform includes three parts: 1) Sensing devices. FMS supports collection of raw data from a variety of mobile sensing devices including smartphones, tablets, GPS loggers and OBD (On-board diagnostics) devices. Smartphone is the main data collection tool due to its high penetration rate and availability of multiple sensors. 2) Backend. Raw data collected via sensing devices is uploaded and stored into a backend database, and a series of algorithms are used to process data and make inferences about locations and times of user stops, travel modes between stops, and activities performed at each stop. 3) User interface. A daily timeline or travel diary based on inferred information from backend is presented to user so that it can be reviewed and corrected. It can also be used to collect additional information that cannot be inferred from raw data. Moreover, the user interface is intended to be customizable to conduct different travel surveys.

To maximize the value of collected data, visualize data and derive insights, the authors developed the FMS Data Fusion and Visualization Platform. It also consists of three parts to manage heterogeneous, multi-source data and provide intuitive visualization. The first part is adaptive data collector that is implemented as middleware to gather data from multiple sources periodically. The second part is a centralized data management platform that provides RESTful APIs for data CRUD operations through HTTP(s) requests and manages multisource data with an interconnected data model. The third part is reusable service modules implemented by the FMS dashboard system for data cleansing, integration, analysis and visualization.

In paper [28] **"A Web-based Diary and Companion Smartphone App for Travel/Activity Surveys,"** Greaves *et al.* reported the development and deployment of an online seven-day travel/activity diary and companion smartphone app in Sydney, Australia. The Web-based Travel Diary used several key features to reduce completion time and improve data quality. First, it will pre-fill or auto-fill the fields based on previous records. Second, repetitive trips could be saved as favorites and recalled for future trips to reduce burden. The authors noted that Email reminders were crucial to participants both at the beginning and in subsequently completing all seven days of the diary.

The optional smartphone app not only could assist participants in recall of their travel but also could verify/correct data collected by the diary. The use of network and Wi-Fi locations provided a better balance between battery life and the need for collecting location data of sufficient quality. Additionally, data from network/Wi-Fi location were often found to have a higher quality than data from GPS in heavily built-up study areas.

The study also reports that 76% of 847 participants completed all seven days and that 16,361 of 16,386 recorded trips were provided with complete details. The completion time of online diary per trip is less than two minutes/trip and three-quarters of the trips were entered within 24 hours of being made. Over half of the participants downloaded the app, which indicated that the app improved the accuracy of trip reporting.

In paper [30] **"Field Evaluation of the Smartphone-based Travel Behaviour Data Collection App 'SmartMo',"** Berger and Platzer developed a user-friendly smartphone-based survey application called "SmartMo" for collecting travel behavior data and they also designed an effective data collection procedure for travel surveys. The SmartMo app has the following main features: First, it has a hybrid, automatic locating system (A-GPS, GSM, WLAN) for route tracking. Second, its asynchronous trip data (e.g., trip purpose, mode of transport) input characteristics allow users especially those under time pressure to postpone entering trip information. Third, it has editing functions (e.g., for completely missing data and editing incorrect travel data) to improve data quality. Last but not least, it implements data privacy and protection strategies (e.g., active tracking, cutting the start and end points of a trip) for data autonomy and security and also energy saving settings for efficient use.

The main results of the field test include: First, the SmartMo app was found intuitive, easy to use, easily comprehensible, and not exhausting users. More than half of the participants reported they enjoyed using the app. Second, data quality could be improved through automatic and objective trip tracking. Daily reminder services such as automatically generated text messages had less or no effects on preventing missing trips. A passive tracking system was likely to help address underreporting. Third, the strategies for privacy protection and data sovereignty were important for the test users and crucial for increasing user acceptance. Finally, very few users had problems with energy consumption of smartphones, which was probably due to the fact that many users had followed the tips for optimizing (e.g., charging overnight) and energy saving (e.g., turning off keypad tones).

In paper [31] **"ATLAS Project - Developing a Mobile-based Travel Survey,"** ATLAS (Advanced Travel Logging Application for Smartphones) project reports an iPhone application designed specifically for performing travel surveys. In ATLAS project, respondents were asked to define trip mode and purpose of each trip-leg independently to increase the accuracy of trip-leg detection and collect their attributes. In addition, all questions were designed in a multi-choice format to save time for answering questions and reduce burden of responding. The ATLAS app was configured to log GPS data of respondent every 10 meters to increase the accuracy of collected data and obtain a precise view over the attributes of each mode. A brief socioeconomic questionnaire was also designed and added in the app.

In paper [33] **"A Seven-Day Smartphone-Based GPS Household Travel Survey in Indiana,"** A team in Anderson, Indiana developed rMove smartphone app to replace traditional telephone and Web based household travel diary survey. rMove uses smartphone's sensors to passively collect location data and uses in-app survey questions to obtain essential HTS data elements (the "why, who, and how" of travel behavior). The app's goal was to prompt respondents to answer those questions in near "real-time" at each trip destination and in a very low burden way, which facilitates those projects with longer data collection periods.

The study on a seven-day smartphone-based HTS was successful on numerous fronts. Almost 90% of the participants were active answering all surveys over the full seven-day period; 71% of trip surveys were answered within five hours of the trip occurring and 17% of trip surveys were completed within 10 minutes of the survey notification. In the follow-up survey, 87% rated their 2015 survey experience easy, 66% rated their 2015 survey experience more fun than their 2014 survey experience, and 52% reported survey requiring less time in 2015 than in 2014. However, the survey in 2014 was a one-day travel diary while the 2015 travel survey spanned seven days. The results suggest reduced burden among participants and a potential of improved accuracy in responses given the small amount of time that elapsed between travel and survey completion.

2.3 Comparison between Smartphone Based HTS and Other HTS Methods

Smartphone based HTS has been compared with other HTS methods, such as traditional household interview travel survey [10] and web-based online survey [20][22][27]. In paper [10] "**Evaluating FMS: A Preliminary Comparison with a Traditional Travel Survey,"** Carrion *et al.* compared two HTS methods, the household interview travel survey (HITS) and future mobility survey (FMS), which took place in Singapore during the 2012 travel survey data collection. HITS is paper-based survey conducted in Singapore every four years for collecting socio-demographic information of the household and individual as well as activity and mobility data for an individual in a typical weekday. The format of HITS is standard trip diary.

The FMS takes a different approach by employing a smartphone app for passive travel data collection, a back-end for mapping, filtering, and analyzing collected data, and a front-end for validating the data with the respondent. Each participant was required to provide at least 14 days of collected data and validate at least 5 of them to receive a monetary incentive. In FMS, a data flagging process was applied to the data validated by participants prior to data analysis. This includes logic checks such as temporal, spatial, and speed checks and identification of the unsatisfactory records and participants that do not meet the minimum requirements.

387 individuals participated in both HITS and FMS and they produced 739 days of 24-hour data. The evaluation results show that most participants reported more trips per day with FMS than with HITS and that the participants often perceive shorter time spent in travel when reporting using HITS.

Lastly, the authors discussed FSM's battery consumption and ease of use issues and concluded that their software implementation could generally achieve reasonable battery consumption. A remote-desktop helpdesk was introduced to help users overcome the learning curve of using the app.

In paper [20] "Comparative Framework for Activity-Travel Diary Collection Systems," Prelipcean *et al.* introduces a comparison framework for HTS systems. The framework can be used to instruct the design of HTS systems and automate systematic analysis of these systems. More specifically, the framework defines several activity-travel diary measurement entities (trips and triplegs) and their attributes (trip purpose, origin and destination). The temporal aspect of a trip/tripleg is described by its start time, end time, duration, and waiting time (between end time of previous trip and start time of current trip). The spatial aspect of a trip is described by its destination, route, length, and nominal variables such as trip purpose and transport mode. Then, the framework measures similarity of two instances of the same entity and find corresponding trips and triplegs in the compared systems. The similarity of trips from two systems is calculated using temporal co-occurrence constraint and identical purpose constraint. It further combines intrinsic and extrinsic indicators of the collected data from the two systems to establishes a ground truth indicator.

The authors presented a case study of comparing two HTS systems: a web-based online survey system PP, and a smartphone-based system MEILI. PP was able to collect 116 trips during the first day of the survey and MEILI collected 97 trips at the same time. After applying the proposed framework, the authors found that MEILI captured more information about triplegs and that the location attributes derived from route agrees more with user annotated data in MEILI than with address specified in PP. In summary, the framework can distinguish entities from the two HTS systems as ground truth and error candidates and can identify strengths and weaknesses of each system.

In paper [22] **"An Empirical Comparison of Four Technology-Mediated Travel Survey Methods,"** Safi et al. evaluated performance of three GPS-assisted methods, i.e., handheld GPS tracking, smartphone-based GPS tracking and smartphone-based prompted-recall data collection methods, as well as a Web-based data collection to understand different aspects of GPS assisted data collection methods. Those methods were compared in terms of quality and accuracy of the collected data, demographic attributes of participants and specifications of labelled trips.

The results show that appropriate use of smartphones can enhances the accuracy. The authors found that extra burden on participants during a travel survey can result in lower trip rates and poor data quality. They also found that the application of smartphone assisted survey methods helps report non-motorized trips more accurately.

In paper [27] **"Enriching Activity-based Models Using Smartphone-based Travel Surveys,"** Nahmias-Biran *et al.* compared the data collected by the Future Mobility Sensing (FMS) method with the data by traditional methods and studied the implications of using FMS data for travel behavior modeling. FMS was field-tested in Singapore in 2012-2013 and a large FMS survey was being carried out in Tel Aviv metropolitan area. The datasets from these two surveys were used to compare against traditional datasets from HTS conducted in Singapore in 2012 and in the Tel Aviv area in 2014.

The paper presents comparative analyses on the rich datasets from Singapore and Tel Aviv, focusing on three main aspects: (1) richness in activity behaviors observed, (2) completeness of travel and activity data, and (3) data accuracy.

The study results show that FMS has clear advantages over traditional travel surveys: First, it has higher resolution and better accuracy of times, locations, and paths; Second, FMS captures out-of-work and leisure activities well; Third, it reveals large variability in day-to-day activity pattern, which is inadequately captured in a one-day snapshot in typical traditional surveys. FMS also captures travel and activities that tend to be underreported in traditional surveys such as multiple stops in a tour and work-based sub-tours. These richer and more complete and accurate data can improve future activity-based modeling.

2.4 GPS-enabled HTS

GPS has been considered as an effective tool for effective travel data collection. Some works focused on reporting the use of GPS devices for HTS and GPR data processing [8][9][26]. In paper [8] **"Prompted Recall Travel Surveying with GPS,"** Auld reported an early attempt on designing an HTS using GPS and Internet-based prompted recall survey. A prompted-recall survey refers to using passive data collection with certain follow-up survey. In this work, passively collected GPS data is used to infer trips and activities taken by the participants and to prompt further responses.

The paper provides in-depth information about the GPS data preparation algorithms, which take as input GPS traces extracted from portable GPS tracking devices. The algorithms then clean input data, derive activity locations, and validate results with user. During data cleaning, obviously incorrect points are removed and errors caused by tracker strays during a short trip or activity are eliminated. A rule-based clustering algorithm is used to find out travel episodes and activity locations. These results are stored in a database and used to build the prompted recall activity survey.

Upon complete of GPS data preparation, a map containing all the trips/activities will be displayed to the participant. The participant is asked to confirm or remove each trip episode. This map and the spatiotemporal display of the trips allow simple schedule correction. Then, the participant is shown a series of questions concerning the attributes, travel modes, or route choice decision of each trip episode. The post-travel survey, combined with previous GPS data preparation, composes an automated prompted recall diary for HTS.

The author also discussed the possibility of using machine learning to reduce respondent burden of completing the survey. One way is to use predictive models to pre-populate question answers based on participant's activity history. Another way is to reduce the number of questions by eliminating those questions whose answer is known with a high confidence, or only asking about unusual activities. In either scenario, participant burden will be reduced through user behavior learning.

In paper [9] **"Deriving and Validating Trip Purposes and Travel Modes for Multi-Day GPS-based Travel Surveys: A Large-Scale Application in the Netherlands,"** Bohte and Maat proposed an HTS method that utilizes GPS logs, geographic information system (GIS) technology and an interactive Web-based validation application. During data collection process, each respondent is provided with a GPS device for gathering GPS logs. The logs, along with individual characteristics of the respondent collected by a survey and GIS data, are stored in a spatial database management system (DBMS). Then, rule-based algorithms process the data and interpret the trip characteristics such as trip modes and purposes. Next, the interpreted trip information is presented to the respondent via a Web-based user interface (UI). The respondent is asked to verify and make corrections and/or additions to the trip information.

Before interpretation of travel characteristics, a GPS log is first split into trips. Specifically, GPS track points inside a building and unrealistic points are removed and then the GPS log is divided into trips; Adjacent trips within the same shopping center are merged. There are also other rules that helps divide trips and clean data. Then, each trip is allocated into one of the 13 trip purpose categories based on the GIS data and predefined rules. Finally, travel mode is calculated from speed data of the trips and GIS data. For example, by checking whether a trip happens along a rail track, the algorithm can distinguish trip by train from trip by car. During validation process, respondents can adjust trip times, travel modes, and trip purposes. They can also merge or split trips, move the location of a trip destination, and even add a whole trip.

The proposed method was evaluated with 1104 respondents in the Netherlands. The results show that the method can correctly derive the travel purpose for "home" and the travel mode of "car" and "bicycle". However, the overall accuracy for travel purpose and mode interpretation is only 43% and 70%, respectively. User feedback indicates little burden for participants to carry and charging the GPS device but medium burden to complete the Web-based trip validation.

In paper [26] **"Global Positioning System-Assisted Prompted Recall Household Travel Survey to Support Development of Advanced Travel Model in Jerusalem, Israel,"** Oliveira *et al.* described an experience with the application of a GPS–assisted prompted recall (PR) method for a large-scale HTS in Jerusalem, Israel. The authors used Voxco's CAPI solution as the survey platform, which provided a main entry point into the survey and managed sample distribution and data synchronization between the field laptops and the survey server. A retrieval tool called TripBuilder developed by GeoStats used data captured by GPS loggers or recorded in travel logs to "prompt" respondents about travel details.

The experience of the first phase of the Jerusalem HTS in 2010 proved feasibility of the GPS-PR method for all population sectors including specific Orthodox Jewish and Arab populations, which typically featured large household sizes. The authors made various structural comparisons of trip and tour rates obtained from the first phase of the Jerusalem GPS-assisted HTS (3,000 households) with those from non-GPS surveys previously implemented in Jerusalem and several metropolitan regions in the US as well as comparisons between the GPS and non-GPS subsamples within the Jerusalem HTS. The results confirmed the ability of the GPS-PR approach to create full and consistent daily records of individual activity travel patterns and to practically eliminate underreporting issues that have plagued HTS.

2.5 Machine Learning for Smartphone based HTS Data Analysis and Visualization

Different machine learning models and algorithms have been developed for different data analysis purposes, including travel mode detection and recognition [13] [14][15][34], human mobility visualization [16], and complete trip information identification [17][32]. In paper [13] **"Transportation Mode Recognition Using GPS and Accelerometer Data,"** to explore the merits of combining accelerometer data with GPS data in transportation mode detection, Feng and Timmermans developed a Bayesian Belief Network (BBN) to infer transportation modes and activity episodes from GPS data, accelerometer data, and the combination of the two. A BBN describes conditional probability and causality relationships between variables. To detect travel modes, the output of the network is the conditional probability of a transportation mode being used, given a certain set of input variables. Modes include walking, running, bicycle, motorcycle, bus, car, tram, and metro. Input variables are derived from GPS and accelerometer data, which provide raw information such as accelerations on the X, Y, and Z axes and statistical information such as average and maximum speeds. The network also incorporates personal characteristics of participant.

In total, 80,670 data records were collected with an accelerometer-enabled GPS device in London area. The dataset was further divided into calibration and validation sets with 65% and 35% of the records, respectively. The accelerometer-only and GPS-and-accelerometer models achieved similar accuracy for the calibration dataset with an accuracy of 96%. However, the accuracy of the GPS-only model was only 81%. The GPS-and-accelerometer model achieved the highest accuracy (85%) among the three for the validation dataset. Regarding detection accuracy for each mode, the accelerometer-only model correctly predicted more than 90% of the records for all the modes except bus and tram. The GPS-and-accelerometer model has a higher detection accuracy for most of the modes. In summary, accelerometer data can substantially improve transportation mode detection accuracy.

In paper [14], **"Travel Mode Detection Based on Neural Networks and Particle Swarm Optimization,"** Xiao *et al.* proposed a Neural Network (NN) algorithm that was trained with Particle Swarm Optimization (PSO) to improve the accuracy of travel mode detection for four travel modes (walk, bike, bus, and car). Compared to rule-based detection algorithms, NN-based algorithms have better generalizability on a variety of datasets. However, the authors pointed out that NNs trained by back-propagation tend to settle in a local optimum, which limits the accuracy of the algorithm. Thus, the paper presents a conceptually simple and gradient free approach to training NN using PSO. The features chosen for detection include the average and median speeds, average absolute acceleration, travel distance, 95th percentile speed, and low-speed point rate. In terms of the architecture of the network, the authors employed a three-layer fully connected network with the logistic activation function. During the training phase, the PSO initializes a swarm of random solutions or particles. A fitness value is calculated for each particle using the root-mean-square-error (RMSE) in every iteration. The particle's best fitness as well as the particle with best fitness in a particle group is also updated accordingly. This fitting process ends when the target criterion is met, or the algorithm reaches its maximal iterations.

The proposed algorithm was evaluated on the dataset generated in a smartphone-based travel survey in Shanghai from Oct. 2013 to Feb. 2014. The dataset was divided into a training set of 1,240 trips and a test set of 414 trips. Compared to other machine learning based algorithms such as SVM, multinomial logit, and NNs trained by back-propagation, the PSO-NN achieved a higher overall classification accuracy (95.81% for the training set and 94.44% for the test set).

In paper [15] **"Developing and Validating a Statistical Model for Travel Mode Identification on Smartphones,"** Assemi *et al.* proposed an algorithm for automated and accurate travel mode detection only using smartphone travel survey data. Many existing smartphone-based HTS studies rely on complementary data sources such as GIS data or follow-up surveys for detecting travel modes. However, such data sources require either participant interactions or expensive communications with third-party service providers

The algorithm consists of the following steps: data cleaning, trip segment identification, variable identification for mode detection, developing initial mode identification models, and adapting the best mode for smartphone integration. In the data cleaning step, inaccurate location log and fake trips caused by position jumps detected by GPS sensor are deleted. Mislabeled travel modes are also examined. Then, GPS traces are split into single mode segments using a trip segmentation algorithm before the data can be fed into mode identification models. Next, a wide range of variables (features) were evaluated to determine the minimal set for accurately identifying the travel mode. The adaptive categorically structured Lasso (CATS Lasso) method was used to determine the impacts of the variables on each potential outcome. Finally, three statistical models were developed to find the most accurate approach for mode identification: multinomial logistic regression (MNL), nested logit, and multiple discriminant analysis (MDA).

To validate the developed models, the preprocessed New Zealand dataset collected using ATLAS II [7] was randomly divided into the training and validation sets. The testing dataset was produced from the data collected by ATLAS II in Australia. The overall mode detection accuracy is higher for MNL and nested logit models compared to the MDA model. The nested logit model was finally selected to be integrated into the smartphone travel surveys. The final model takes eight variables into consideration including the skewness of the speed distribution, maximum speed, and acceleration variance. In conclusion, the proposed algorithm for detecting travel modes can achieve an accuracy of 97% for the New Zealand dataset and 79.3% for the Australia dataset.

In paper [16] **"Not All Those Who Wander Are Lost: Exploring Human Mobility Using A Smartphone Application,"** Borsellino *et al.* visualized human mobility patterns from the data collected using smartphone app Wander during a pilot study. Wander captures participants' timestamped geolocation passively and prompts participants to upload their traces at the end of each day. There was also a user interface displaying the current location on a map. The researchers collected a sample of 24 participants using Wander as well as the Australian Bureau of Statistics 2011 census data at the mesh block for identifying land use. These two datasets were integrated using ArcGIS. Then, analytic techniques such as convex hulls, circular time series plots, and kernel density estimates were applied to visualize and contextualize the spatiotemporal dynamics of the traces.

The authors presented a detailed analysis of the survey result. They first examined aggregated statistics of the traces such as the number of traces uploaded and size of activity space for each participant. The activity spaces vary greatly across the sample and may depend on a participant's socio-demographics, household composition, and access to various forms of transportation. Regarding land use, the analysis shows that residential usage peaks at night and commercial, parkland, and industrial land usage peak from morning to evening. An unexpected finding was that educational facilities show a high-level of mobility at night, probably because part of the residential areas such as on-campus dormitory was counted as educational facility. A hotspot map was derived from the survey data to show the intensity of visitation of points of interest (POI). Similarly, a temporal distribution of spatial occupation could also be extracted to visualize diurnal patterns of mobility on the hotspot map. Finally, the authors also discussed the advantages and limitations of using smartphone technologies for HTS. On one hand, a smartphone based HTS reduces participant burden and survey cost and increases richness and resolution of collected data. One the other hand, obstructions of GPS signal may produce recording errors. The battery life and data privacy are also major concerns for smartphone based HTS.

In paper [17] **"An Automated Approach from GPS Traces to Complete Trip Information,"** Yazdizadeh *et al.* developed a machine learning based framework to identify complete trip information from smartphone location data and other online data sources. The goal of their research is to demonstrate the possibility of deriving all critical information from large-scale smartphone travel survey data without participant interactions such as CATI or mail-back surveys. The study used the MTL Trajet [18] HTS data, Transit Itinerary Inference (TII) survey data [19], Montreal land-use data, Foursquare data describing venue information of a given location, General Transit Feed Specification (GTFS) data, and Bing elevation data to approximate the maximum and minimum slopes of the earth along a trip for travel mode detection.

A data preparation process was first applied to the MTL Trajet dataset to detect trips and segments. Validated travel mode data was also derived from the survey questions. Next, a Random Forest (RF) model was generated based on the validated MTL Trajet trips to predict travel modes of those trips in five categories: walk, bike, car, public transit, and "car and public transit".

The features used in the classifier include trip characteristics such as 85th percentile speed and max/min acceleration. Next, another RF classifier, along with reference data from GTFS-based transit network and street network from OpenStreetMap, was used to detect transit itinerary of a trip. A graph search algorithm from OpenTripPlanner was also used. Finally, the MTL Trajet, FourSquare data, and land-use data were fed into a third RF to infer the activity (trip purpose).

The proposed model was validated using a ten-fold cross-validation against the participant-annotated MTL trajet data. The results show that the RF models can predict the travel mode, transit itinerary, and trip activity with an overall accuracy of 87%, 81%, and 71%, respectively. The authors compared their results with previous studies and concluded that their results compare well with others.

In paper [32] **"Automatic Trip and Mode Detection with MoveSmarter: First Results from the Dutch Mobile Mobility Panel,"** Geurs *et al.* proposed MoveSmarter that can automatically detect departure and arrival times, trip origins and destinations, transport modes, and travel purposes. MoveSmarter offered the following features: automatic trip registration, update of the detected trip characteristics on a back-end service, and an Internet-based prompted recall survey provided by CentERdata. The update of trip characteristics includes filtering, cleaning, map-matching and data enrichment and the transport mode deduction uses Bayesian probability statistics by considering speed patterns, sensor data characteristics, infrastructure network, public transport information, and personal trip history. Respondents can access the survey webpage to check, revise, add/delete, and approve the MoveSmarter trip detections. MoveSmarter was regarded as a promising alternative or addition to traditional trip diaries by reducing respondent burden and increasing accuracy of measurement. However, there was still room to improve trip and mode detection and efficiency of battery consumption.

In paper [34] **"Ensemble Convolutional Neural Networks for Mode Inference in Smartphone Travel Survey,"** Ali *et al.* developed ensemble convolutional neural networks (CNNs) to classify the transportation mode of trip data collected as part of a large-scale smartphone travel survey in Montreal, Canada. Their proposed ensemble library was composed of a series of CNN models with different hyper-parameter values and CNN architectures. In the final model, they combined the output of CNN models using "average voting," "majority voting," and "optimal weights" methods. Furthermore, they exploited the ensemble library by deploying a random forest model as a meta-learner.

The researchers used GPS data collected by the smartphone travel survey app, MTL Trajet, which is an instance of the smartphone travel survey platform, DataMobile/Itinerum. MTL Trajet was released as part of a large-scale pilot study on the 17 th of October 2016 in a study that lasted 30 days. Over 8,000 people participated in the study.

Their ensemble method with random forest as meta-learner shows an accuracy of 91.8% which surpasses the other three ensemble combination methods, and other comparable models reported in the literature. The "majority voting" and "optimal weights" combination methods result in prediction accuracy rates around 89%, while "average voting" is able to achieve an accuracy of only 85%.

2.6 Other Aspects

Other aspects of HTS have also been discussed in some papers, including multimodal travel behavior [2], respondent/survey interaction [4], participants' perceptions [5], impact of trip underreporting [21], and increasing survey participation rate [29]. In paper [2] **"Capturing and Representing Multimodal Trips in Travel Surveys**]," as an often underrepresented topic in HTS research, the travel survey practices for multimodal travel behavior was reviewed. A multimodal trip is a tour that consists of multiple stages, where each stage is represented by an activity that starts from the initial location of the trip or the location of the previous stage. It usually includes walking, bicycling, short vehicle trips, or transit access and egress segments. For example, going to work can be a multimodal trip if it consists of multiple connected stages such as riding a bicycle from home to train station A, taking a train from train station A to station B, and walking from station B to workplace. The transportation modes in the above multimodal trip are bicycling, public transit, and walking. Understanding the main and complementary modes can benefit transportation modeling, infrastructure planning, urban designing, and health research communities.

Multimode travel behavior can be collected via HTS using the following methods: stage-based surveys, activity-based surveys, trip-based surveys, and tour-based surveys. All the four methods allow recording multimodal trips, but the authors found that most household travel surveys using these methods provide little guidance on collecting information about multimodal trips. Emerging technologies used in HTS such as GPS and smart card fare systems, as well as data structure for HTS, are also discussed in the paper. In conclusion, the authors suggested HTS designers give more consideration on including multimodal trips in their survey and establish a clear guidance on how to collect such trip information.

In paper [4], **"Workshop Synthesis: Respondent/Survey Interaction in a World of Web and Smartphone Apps,"** Silva and Davis explored respondents' interaction with Web and smartphone-based travel surveys and common concerns including survey design, sample representativeness, privacy, respondent burden, data quality and validation. As the Internet and smartphones become more and more available, the interest of using these modes for travel behavior data collection, as well as the challenges on interaction between these tools and survey respondents, is increasing. Adopting these new technologies in HTS needs to address the following challenges: 1) Smartphone battery consumption, which could be mitigated by the development of battery technology and optimization of mobile operating system. 2) Data quality issue caused by precision degradation and signal loss of GPS devices associated urban canyoning effects. 3) Designing the survey app that can run simultaneously with other software and run on different operating systems. 4) Collecting supplementary data such as trip purpose and traveler information while balancing resource efficiency, participant burden, and data accuracy. 5) The bias due to the Internet and smartphone penetration and its effects on sample representativeness. 6) Privacy and ethical issues such as gaining respondents' trust and complying with privacy laws. 7) Other risks including respondent safety when interacting with a smartphone while traveling and the potential for improper access to respondent data by third parties.

Regarding reducing participants' burden, this work suggests increasing passive data collection or respondent enjoyment and interest to improve their engagement. Given that data collected through Web and smartphone surveys can be rapidly and easily processed, survey designers can provide instant and useful feedback such as current location and travel statistics to users to keep them engaged. Finally, the authors also discussed the considerations of validating HTS data using complementary surveys and multiple data sources.

In paper [5] **"Participants' Perceptions of Smartphone Travel Surveys,"** Assemi *et al.* studied the impact of an individual's subjective perceptions and attitudes on their HTS participation intentions and behavior. They suggested that people's participation in such surveys can be significantly affected by their level of technology acceptance. As the technology acceptance model [6] points out, an individual's satisfactory with a technology and his/her willingness to use it are affected by his/her perception of the "ease of use" and "usefulness" of the technology. The satisfaction in turn also affects the individual's intention of keeping using the technology.

The authors proposed a smartphone travel survey participation model, which assumes that users' perceived ease of use and usefulness of the survey app contribute positively to user satisfaction, and the user satisfaction is positively associated with their intention to continue participating in the survey. Meanwhile, users' perceived risk is negatively associated with their participating intention.

To validate the proposed model and measure participants' intentions and attitudes towards the survey app, the authors conducted a survey. The participants were first asked to use the Advanced Travel Logging Application for Smartphones II (ATLAS II) [7] for two weekdays to record their travel activities. Then, they were asked to complete an online survey about their perceptions on the survey and participation intentions. The collected data was analyzed using the partial least squares path modelling (PLS-PM). The results reveal that the participants' perceived "ease of use" and "usefulness" of the survey app have a significant positive impact on their "satisfaction" and "continuance intention" of participating the survey. Moreover, the perceived risk of privacy breaches does not have any significant impact on their intentions.

In paper [21] **"The Impact of Trip Underreporting on VMT and Travel Time Estimates Preliminary Findings from the California Statewide Household Travel Survey GPS Study,"** Wolf *et al.* presented an analysis of the impact of trip underreporting on modeled vehicle miles of travel (VMT) and travel times from the California Statewide HTS GPS Study. The authors compared estimates of VMT and travel time derived from traditional travel survey results, which were obtained using Computer Assisted Telephone Interviewing (CATI) and generated within travel demand models, with GPS-measured VMT and travel time.

CATI and GPS data collection took place over a period of 20 weeks in three regions (San Diego, Sacramento, Alameda) in California. For the CATI-reported trips, the initial step of data preparation involved geocoding reported trip ends to participating regions' TAZs. These trips were then loaded, according to their time periods, into the region's transportation model's network, which produces transportation model derived distance and travel time for each reported trip. To obtain GPS-based trip distance and travel time, the GPS data streams collected in participating households' vehicles were processed using GeoStats' Trip End Analysis (TEA) software to identify trips and trip level detail including trip distance and travel time.

In areas with high levels of underreported trips, such as Sacramento, the impact of these missed trips on modeled VMT was predictable, with 3,008 miles of modeled VMT compared to 4,235 miles of GPS measured VMT from the same households. Similarly, Sacramento's households accounted for 4,673 total modeled travel minutes, whereas the GPS measured trips had 5,259 total minutes. Alameda's trends were consistent with Sacramento. However, the results from San Diego appeared counterintuitive when only trip details were considered. Although a net increase of 135 trips were added in the GPS analysis, the impact on total VMT was a negative 30 vehicle miles. A possible reason is that different regional travel demand models produce estimates of VMT and travel time that vary considerably with respect to GPS measured data.

In paper [29], **"Increasing Smartphone-based Travel Survey Participants,"** Maruyama *et al.* reported two smartphone-based travel surveys conducted in Kumamoto, Japan and proposed several approaches to increasing participants in smartphone-based surveys. The first survey was the visitors' behavior survey in downtown Kumamoto and collected 1,086 samples. The second survey was the truck floating car survey, in which seven logistic companies were asked to participate and 21 samples of five days' behavior were used.

The authors obtained the following findings from the visitors' behavior survey in downtown Kumamoto: First, they collected a large sample size using courteous requests and rewards. Second, they found that participants' attitudes on reward differed. Young people preferred rewards while some aged people thought that rewards did not matter. Third, they found that posters and flyers of the survey were effective for people around 40-59 years old.

Regarding the truck floating car survey, the authors found that it is important to inform respondents and their company how survey methods work. Compared to the first survey, rewards might not be necessary for participants in the truck floating car survey. The study also indicates that the survey request by local government and local trucking association was effective.

Chapter 3 Methodology

In this chapter, we first present the design of our HTS@TN application in Section 3.1 and then describe our pilot HTS study using the HTS@TN application in Section 3.2.

3.1 Design of HTS@TN Application

HTS@TN is a smartphone app-based application using the client-server model. It consists of two mobile apps, one for Android and the other for iOS, as well as a web app at the client side and a server and a database at the server side. It is designed to support household travel surveys with different lengths, from several days to several months.

3.1.1 Workflow of HTS@TN based Household Travel Survey

The workflow of household travel survey using the HTS@TN application consists of four phases: 1) pre-survey interactions, 2) household recruitment survey, 3) travel data collection, and 4) post-survey interactions, as illustrated in Figure 3-1. This workflow is similar to the survey method described in [24].

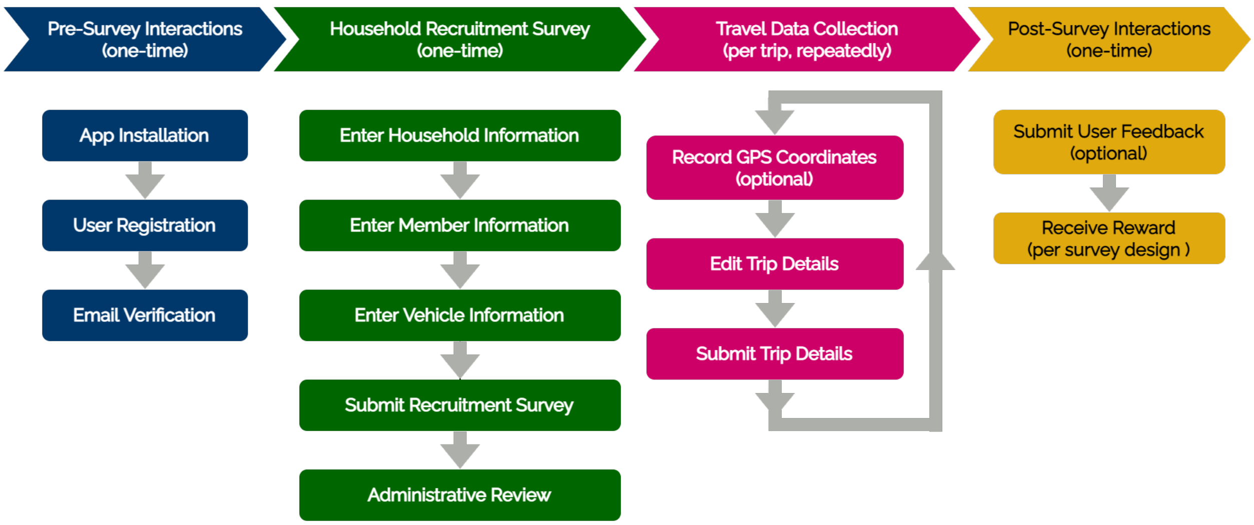

Figure 3-1 Workflow of Household Travel Survey Using HTS@TN

Pre-Survey Interactions. In the first phase of a household travel survey (HTS), the survey is anticipated to be advertised for recruiting participants via multiple channels such as social media and onsite promotion. People who are interested in the survey are instructed to download the HTS@TN mobile app from Google Play or Apple App Store and install it on their smartphones. To secure user data and filter out spams, interested people need to register an account through the mobile app with their email address and password. A registration code provided by the HTS organizer may be used during the registration, which can be used for analysis of channels through which the survey information is distributed. Unlike other research such as [30], the use of registration code is optional in HTS@TN, which aims to lower the barrier and attract more people to participate in the survey. A person will be enrolled into a survey only after his/her household recruitment survey has been accepted. Potential participants will also need to read and accept the provided policy documents including Terms of Service, Privacy Policy, Acceptable Use Policy, and User Informed Consent before submitting their information on the mobile app.

Once a new account is created, an email with a verification link will be sent to the user's registered email address for verifying that email address and completing the account registration. The email verification is essential to ensuring users have access to their registered email account so that they can recover their accounts and receive important updates and instructions about the survey.

Household Recruitment Survey. The second phase begins after a successful account registration. HTS@TN users who want to participate in an HTS survey will be asked to first complete and submit a household recruitment survey through their HTS@TN mobile app. The household recruitment survey questions are derived from the 2017 National Household Travel Survey[1]. In this survey, a user will need to provide 1) household information including household address, housing type, and household income, 2) personal information for each household member, such as age, gender, and occupation, and 3) household-owned vehicle information, e.g., vehicle make, model, and year. All the questions in the household recruitment survey were reviewed and approved by TDOT. Refer to Appendix A for the complete list of household recruitment survey questions. A user can choose to save the survey answers and come back later or to submit the completed survey. Submitted recruitment surveys will be manually reviewed. Based on a user's household recruitment survey answers, a decision will be made regarding whether to accept the user into the HTS and a notification email will be sent to the user's registered email address. Section 4.2.1 presents the results of household recruitment survey from the pilot study.

Travel Data Collection. Once a user's household recruitment survey is approved, the user becomes a survey participant, and the workflow proceeds to the third phase. In this phase, a survey participant is expected to actively log his/her trips using the HTS@TN mobile app for a given period of time. For the pilot survey study, we set seven days, the same as many related studies [23][28][33]. For each trip, a user may choose to enter trip details manually in the mobile app or use its built-in automatic trip tracking function to record a trip trajectory and edit the trip details later. The analysis of trip data collected from the pilot study is given in Section 4.2.2.

For manual input, an app user is anticipated to provide the start and end locations of a trip and also enter partial or full detail of the trip, such as trip purpose, trip mode, distance, and so on. Refer to Appendix B for the list of questions for a trip log. The user may also tap the "Track Trip" button on the HTS@TN app to begin automatic trip tracking. Automatic trip tracking is achieved by utilizing multiple location sensors on device, including GPS, Wi-Fi, and cellular signals, etc. As shown in previous research, a multi-sensor-based travel data collection provides data of equal or even better quality than the data collected by GPS only [23]. During trip tracking, the app will report the geolocation, speed, and bearing of the smartphone periodically with a fixed interval (e.g., 10 seconds). The app will also try to decode the start and current geolocations into text addresses so that it can autofill part of the trip information when the tracking stops. When a trip finishes, a user can choose to complete its trip log right away or complete/refine the trip log later. The trip created by the automatic trip tracking feature will be uploaded to the server only after the user reviews and saves the trip information. Then, a completed trip log will be submitted to the HTS server and saved in the backend database. Uploaded trips can be viewed and examined

[1] https://nhts.ornl.gov/

through the HTS@TN app, and survey participants can also revise or remove their saved trips during the survey period.

Post-Survey Interactions. A survey participant can provide his/her feedback on the app at the end of a survey by rating the app's functionality, usability, and stability and commenting freely in the user feedback survey embedded in the mobile app. The ratings are in the Likert scale where 1 indicates that the user is least satisfied with the item being rated and 5 means most satisfied. Section 4.2.4 provides the detail of user rating of the app from the pilot study.

After completion of a survey, if the survey provides rewards, selected participants may be rewarded if their participations meet all the requirements for receiving a reward. For example, submitted trip logs can be used as part of the criteria for selecting reward candidates. If selected, a participant can be notified of their reward via their registered email address. Note that reward requirements/criteria are up to a survey design and out of the scope of this research.

3.1.2 Design of HTS@TN Server and Apps

The HTS@TN application is based on the classic client-server model. The high-level overview of its system architecture is depicted in Figure 3-2. The HTS@TN server processes requests from HTS@TN mobile and web apps and stores/retrieves user-generated survey data into/from a database. The mobile apps are responsible for providing a user-friendly interface for app users to participate in an HTS and record their trips. The HTS@TN apps communicate with the server through a REST (Representational State Transfer) application programming interface (API) designed for the HTS@TN application. All communications between HTS@TN apps and the server are secured by HTTPS. Apart from that, the HTS@TN system incorporates several third-party services such as Google Maps API service to provide functions needed for the HTS operations.

The HTS@TN server provides a list of REST API endpoints to the HTS@TN mobile and web apps so that they can easily retrieve and upload household recruitment survey answers, trip details, user feedback, and other user-generated data. All data is persistently stored in the backend database. Frequently requested data are also temporarily stored in the cache storage to improve system performance and user experience. To reduce system complexity and leverage mature, free third-party email services such as Gmail, the HTS@TN server utilizes a third-party email service for sending notification emails to users.

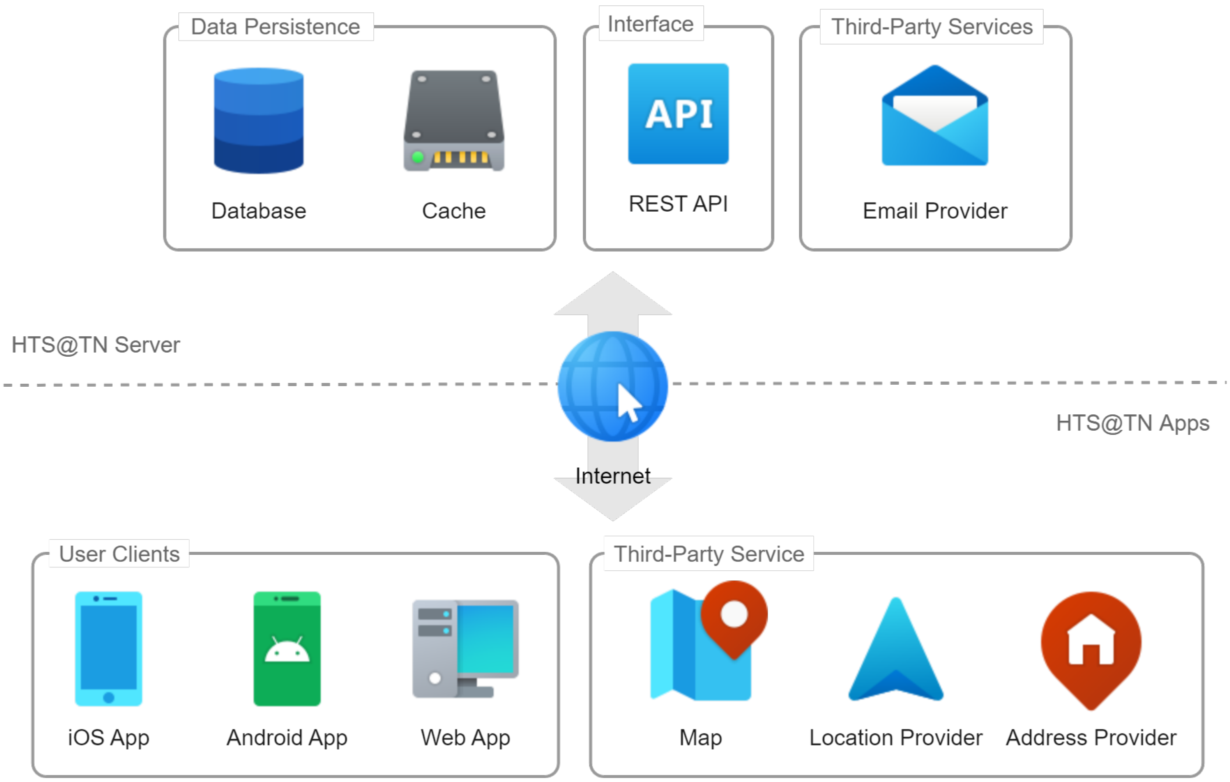

Figure 3-2 High-level Overview of HTS@TN System Architecture

The data format and variables from the National Household Travel Survey served as a guidance in the database design. The objects in the database including tables, indices, views, variables, and so on were carefully designed to achieve efficient data management, increased data sharing, and high data quality. In addition to survey answers, the server also stores trip GPS coordinate data collected by mobile apps as time series data in a separate database table. Each coordinate is a combination of latitude, longitude, altitude, time, and some other metadata of a location. A UML diagram of design of trip related database tables is depicted in Figure 3-3. Refer to Appendix D Database UML Diagrams and Tables for more detail about the database design.

Since Android and iOS have been the most popular and dominant mobile operating systems (OS), we decided from the very beginning of this project that the HTS@TN mobile app should be available on both Android and iOS platforms. Moreover, the mobile apps on Android and iOS should have highly similar user interface (UI) and same set of functions and features whenever possible. In other words, an Android app user should have no difficulty in using the app on an iPhone.

Besides the mobile apps, the HTS@TN system also includes a web app, which provides the homepage of the project as well as an administrative dashboard. The dashboard can be used to review submitted household recruitment survey answers and approve or decline the enrollment of a user in the survey. The dashboard can also display all or selected trips uploaded by survey participants based on specified filtering criteria. Both the mobile apps and the web app use third-party services such as map and location service and address service to implement necessary functions for best user experience.

Figure 3-3 One of the UML Diagrams for HTS@TN Database Design

3.2 Pilot HTS Study Using HTS@TN

3.2.1 Design of Pilot HTS Study

A pilot HTS study is also included in this research project to test the efficacy of the developed HTS@TN application. The process of performing the pilot HTS study consists of the following steps: 1) determining the survey scope and duration, 2) obtaining all necessary approvals for the survey from both TDOT and UTC including UTC Institutional Review Board (IRB) and UTC Finance and Administration, 3) deploying the HTS@TN application in a production environment at UTC, and 4) launching the survey, recruiting survey participants, checking survey progress, and performing necessary processing and related activities during the survey period. Step 3 can start early and be conducted in parallel with Step 2. In practice, Step 3 did start early and was completed before Step 2 finished. Survey data analysis is not part of the pilot study due to time limitation.

The pilot HTS study was designed as a 2-stage survey in which UTC students/employees were the primary target population in the first stage while Tennessee residents in general as well as UTC students and employees were targeted in the second stage. The 2-stage design was aimed to provide the HTS@TN application with a relatively small and uniform survey population to start with and to evaluate its performance when the user base became much larger and more diverse. Two different referral codes, UTC2022 for UTC students and TN2022 for Tennessee residents, were provided to survey participants for them to voluntarily enter during their account registration, which would help survey data analysis. To account for travels across the state border, not only Tennessee residents but also residents in one of the Tennessee neighboring states were allowed to participate in the pilot survey study. The pilot survey began on April 12 and ended on July 11. The second stage started in the middle of May. All survey participants were required to use the mobile app for seven consecutive days upon their recruitment survey was approved, no matter in which stage.

A number of important approvals were needed from UTC and TDOT before the pilot survey could be launched. First, the IRB application for the pilot survey must be approved by UTC IRB, which was completed in 2021. Second, we had to obtain an approval for using the funds to purchase Amazon gift cards as survey rewards from UTC Finance and Administration. Third, the survey also had to be approved by the TDOT leadership. Finally, there were other approvals related to the survey we sought from the TDOT staff members involved in this project such as survey questions, survey flyer design, etc. All the necessary approvals were obtained before the survey was launched at UTC in April 2022.

The deployment of the HTS@TN application is detailed in the next section. Section 3.2.3 presents the recruitment of survey participants.

3.2.2 Deployment of HTS@TN Application

We deployed the HTS@TN server on a virtual machine (VM) hosted at the University of Tennessee at Chattanooga (UTC) with the help of UTC IT. The VM was equipped with two virtual CPU (vCPU) cores, 4 GB memory, one 10 Gbps network connection, and a 400 GB hard drive. A network file system (NFS) partition was also mounted on the VM to store database backups. The VM ran Oracle Linux Server 8.6 operating system. For security reason, the VM was placed behind the UTC network firewall and only HTTP port 80 and HTTPS port 443 were exposed to the Internet.

Requests to the HTTP port were automatically redirected to the HTTPS port. The domain name for the VM was set to "tdotproject.research.utc.edu" and a digital certificate for the domain name was acquired and installed. Secure shell (SSH) based remote accesses to the VM were only allowed on the UTC campus network. For SSH remote accesses from off campus networks, a virtual private network (VPN) connection must be established first.

The server VM hosted two important services: the HTS@TN server and web app. The HTS@TN server consists of three interconnected backend services: the REST API server, the PostgreSQL database, and the Redis cache server. All the three services ran inside lightweight Linux containers managed by Docker. The advantages of deploying such services in containers include 1) strong consistency of service runtime environments independent of host hardware and operating system, 2) reduced attack surface thanks to services contained in isolated internal networks, and 3) shorter deployment time by virtue of container automation. To securely expose the developed REST API to the Internet, a Nginx reverse proxy was used to route web traffic reaching the host to the REST API server container. The HTS@TN web app is a set of static webpage files including HTML, JavaScript, Stylesheet, and other asset files. Upon deployment, the source code of the web app was compiled to static files and those files were hosted by the same Nginx server. A screenshot of the homepage of the deployed web app is shown in Figure 3-4.

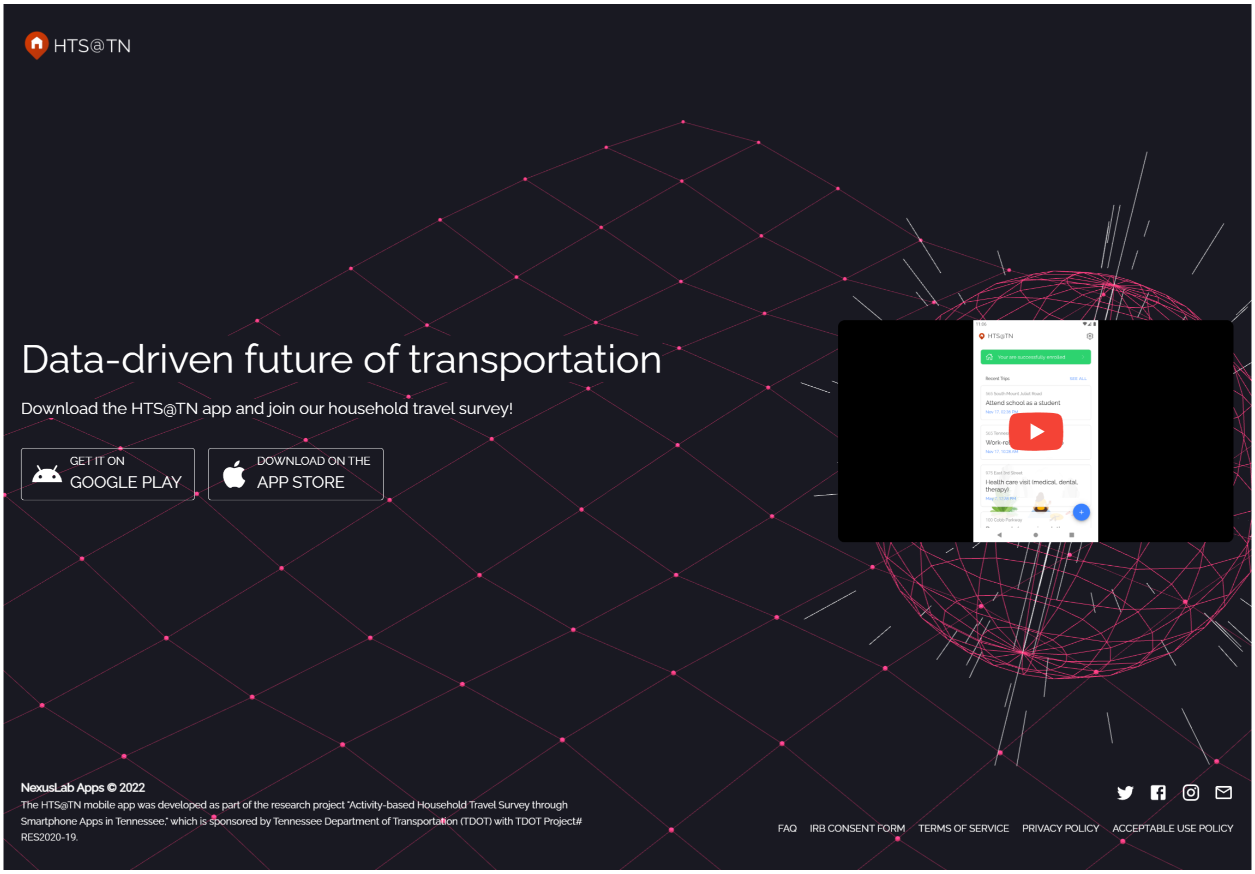

Figure 3-4 Homepage of HTS@TN Web App

The HTS@TN Android and iOS mobile apps were developed and built on an Apple Mac mini computer with one 6-Intel core i7 processor, 16 GB memory, and 500 GB solid-state drive (SSD).

Its operating system was macOS Monterey. The Android and iOS apps were compiled using up-to-date Android Studio and Xcode, respectively. To publish these apps on official mobile app stores of their corresponding platforms, we signed up for a Google Play developer account and an Apple developer account and we purchased their developer licenses. In addition to uploading the built app installation packages to each app store, the detailed store listing information such as app description, screenshots, developer contact information, and legal documents were also provided to the stores for review. In the meantime, we set up internal testing channels for both Android and iOS apps to collect feedback on them before they were released to the public. After the app reviews were passed and the pilot survey study was ready to launch, we published the HTS@TN mobile apps on Google Play and App Store. The screenshots of the HTS@TN mobile app published in Apple App Store and Google Play are shown in Figure 3-5. Once the mobile apps are released to the public, they can be downloaded and installed on a compatible smartphone just like other mobile apps. If a new version of the mobile app is developed for certain updates, the newer version will go through another round of review and approval process for both App Store and Google Play before it is published in either of the app stores. The HTS@TN mobile app will be automatically updated to the newer version during app updates if a newer version has been released.

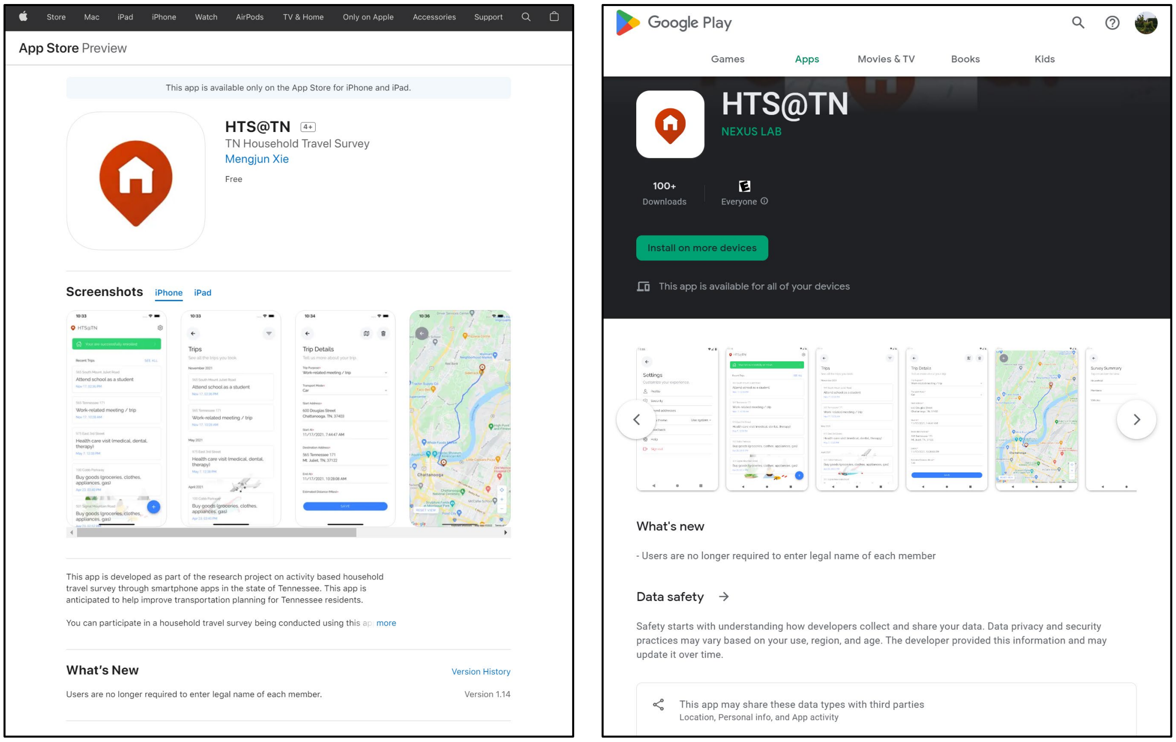

Figure 3-5 Screenshots of HTS@TN Mobile App in Apple Store (left) and Google Play (right)

Finally, several third-party services that are essential to the functionality of HTS@TN apps were subscribed in the deployment. These services include Google Maps JavaScript API, Places API, Geocoding API, and Gmail. The Google Map APIs allow the mobile apps to display interactive maps, provide address auto-completion, and translate geo-coordinates to an address and vice versa. Gmail was used for sending automated email such as email verification and survey enrollment notification email to users. These services were configured in the HTS@TN server and apps via their corresponding configuration files.

3.2.3 Recruitment of Survey Participants

Recruitment of survey participants is a challenging task for survey studies. As mentioned in Section 3.2.1, the pilot survey has two stages where the main approaches to recruitment of survey participants differ in the two stages.

In the first stage, as UTC students/employees were the target population, the following means for recruitment were used:

- Distributing survey flyers on UTC campus
- Promoting the survey through exhibition booth on campus
- Sharing survey information through UTC email
- Sharing survey information through project website
- Promoting the survey on social media (e.g., Facebook)

Figure 3-6 One of the Flyers for the Pilot Survey

In April and May of 2022, after the survey was officially launched, we conducted many different activities to promote the pilot survey on UTC campus, including posting multiple survey flyers in UTC academic buildings, student centers, and dormitories, setting a booth in different locations to promote the survey several days a week for multiple weeks, sending email about the survey, as well as posting on Facebook and Instagram. However, those means were not effective in terms of the number of participants enrolled during that time period (see Section 4). Figure 3-6 shows one of the flyers that were posted on UTC campus, which were also posted on social media during the pilot survey. For social media promotion, we created a Facebook Page, an Instagram account, and a Twitter account for the survey and made several posts on Facebook, Instagram, and Twitter.

In the second stage, as Tennessee residents were targeted, we shifted survey promotion focus and efforts more on social media, news channel, and email. Distinct from the social media promotion in the first stage, which only relied on self-promotion, the social media promotion in the second stage relied more on other public social media accounts such as TDOT accounts and paid advertisements, which turned to be much more effective. Figure 3-7 shows a Twitter post made by TDOT (using Twitter account myTDOT) on May 31, 2022 for promoting the pilot survey. More sample images used in survey promotion on social media are provided in Appendix E.

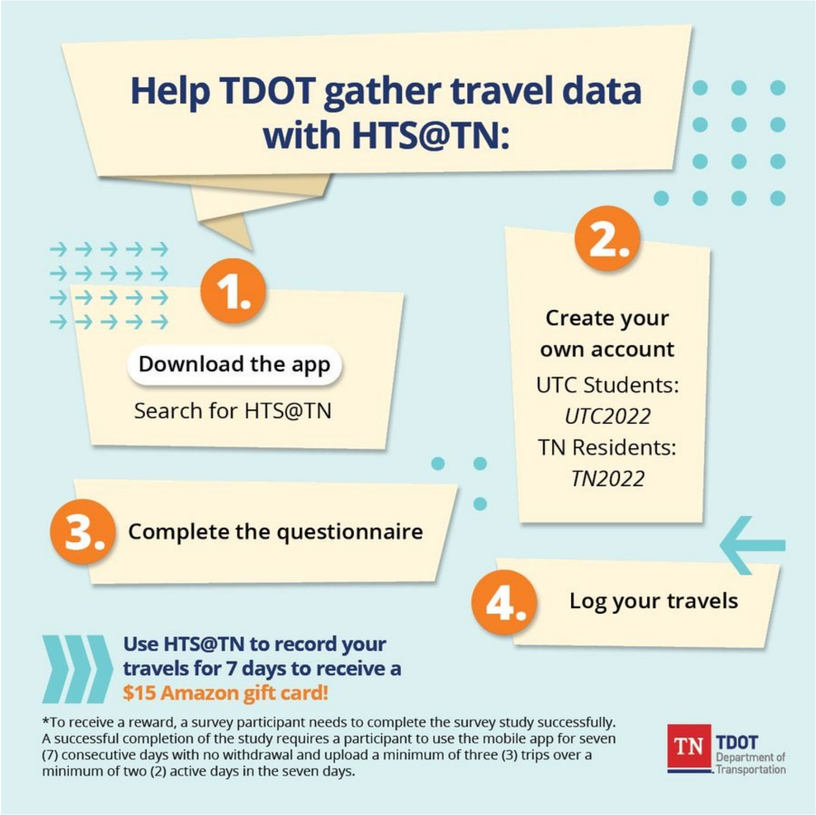

Figure 3-7 Survey Promotion Post on Twitter by myTDOT

Due to the TDOT Twitter post, an interview on this project was made by Chattanooga's Local 3 News and broadcasted on June 1, 2022. A surge of the number of submitted recruitment surveys were witnessed afterwards, suggesting that TV News be an effective means for survey promotion.

Email was continuously used in the second stage. Survey promotion email was not only distributed on UTC campus but also shared with the Tennessee Model Users Group (TNMUG). Although we initially intended to share the pilot survey information in other colleges/universities in Tennessee, we soon found that it is not feasible to do so.

Chapter 4 Results and Discussion

The research results from this project as well as relevant discussions are presented in this chapter. Section 4.1 presents the results of development of the HTS@TN server and apps. Section 4.2 reports the results from the pilot HTS study. More specifically, Section 4.2.1 details the statistics of the recruitment survey data; Section 4.2.2 presents the analysis of reported trips; Section 4.2.3 lists the statistics of the Google APIs used in the study; Section 4.2.4 discusses the user feedback on the HTS@TN mobile app; Last but not least, Section 4.2.5 describes the results from the social media advertisements for promoting the study and recruiting participants.

4.1 HTS@TN Server and Apps

The development of the HTS@TN application in general followed the classic waterfall software development model; the development process consisted of analysis, design, implementation, testing, and operation. Section 3.1 presents the design of the application and Section 3.2.2 describes the deployment of the application for the pilot study. This section presents the implementation and testing of the application. Regarding the performance and user feedback of the application from its operation in the pilot HTS, refer to Sections 4.2.3 and 4.2.4.

The HTS@TN server-side functionality was implemented in approximately 16,200 lines of TypeScript code and thousand lines of code in other programming languages. The backbone of the HTS@TN server is NestJS, which is an efficient framework for building server-side applications in TypeScript. The TypeScript code is compiled to JavaScript and then runs on Node.js, which is a high-performance JavaScript runtime for server-side applications. In addition to the HTS@TN server, a PostgreSQL database server was also used as the centralized storage for user-generated data and a Redis cache server was used for accelerating retrieval of frequently used data.

The HTS@TN server primarily provides the REST API service to the HTS@TN apps. The advantages of using RESTful API in the HTS@TN application include 1) better scalability for large operations, 2) greater flexibility in the choice of technology stack, and 3) reduced complexity of server-client communication. The HTS@TN server APIs are strictly categorized by the resource types they manage, among which the most important ones are households, members, vehicles, and trips. Each type of resource can be managed using four operations, including 1) reading one or a list of resources, 2) creating a new resource, 3) updating an existing resource, and 4) deleting a resource. All requests and responses of the HTS@TN server are in the JavaScript Object Notation (JSON) format, which can be easily parsed and validated by the server and apps.

In addition to the NestJS framework, we also used other open-source libraries in the HTS@TN server implementation for authenticating users and validating user input data. For example, the server validates phone numbers with a phone number parsing library from Google. It also issues and verifies user authentication tokens using Passport.js. One notable service in the HTS@TN server is SMTP, which is essential for sending automated email messages to users. The SMTP acts as an email client that connects to the Google Gmail service. However, the choice of SMTP service provider is fully configurable in the configuration file.

Most functions of the HTS@TN apps were also implemented in TypeScript, with parts of the Android and iOS apps written in platform-native code. The total number of lines of the TypeScript code in the HTS@TN apps is around 13,100, with nearly 1,000 lines of Java code for the Android app and 600 lines of Swift code for the iOS app.

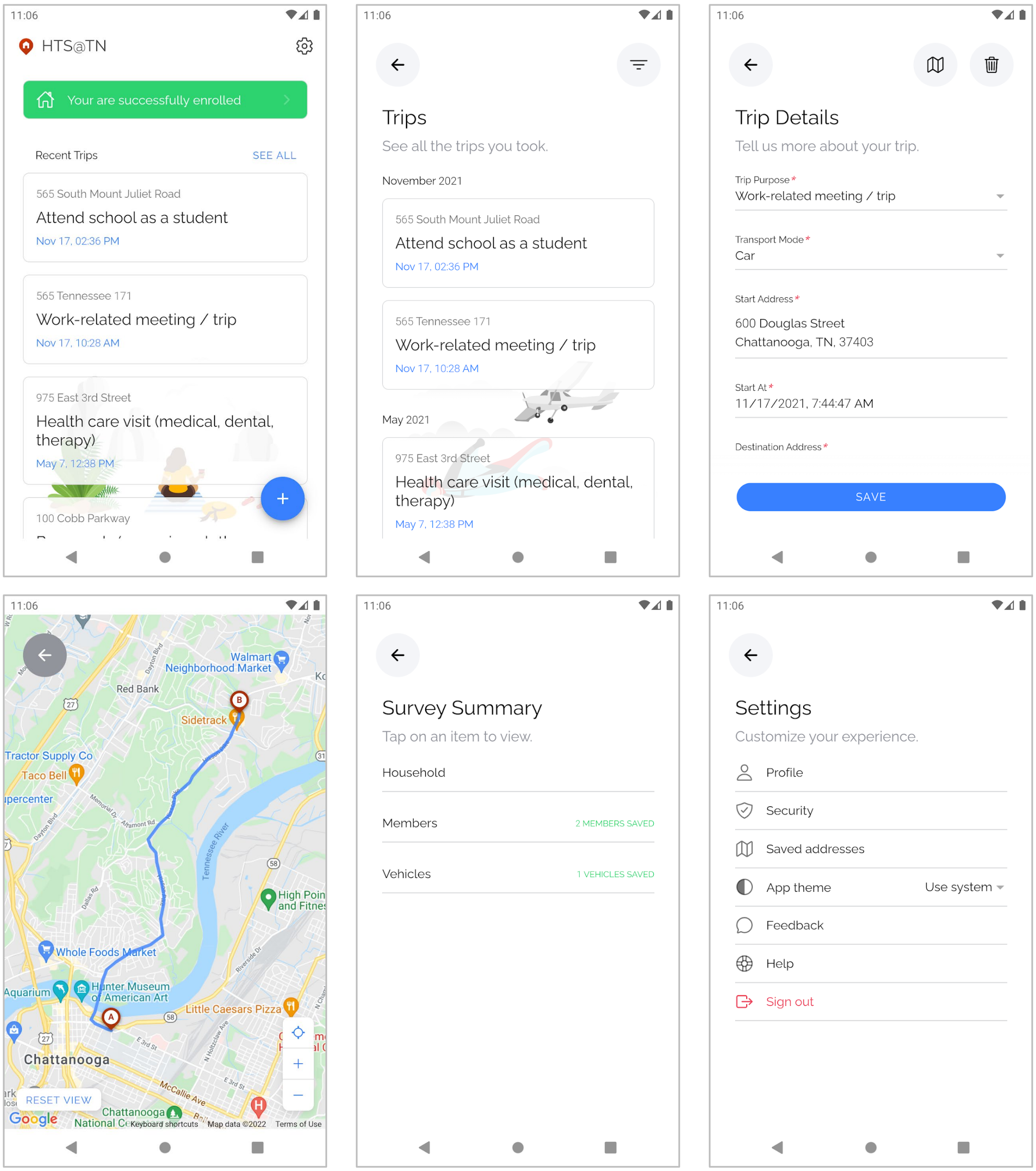

Figure 4-1 User Interface (UI) of the Implemented Android App

To achieve a uniform user experience across the Android and iOS apps and expedite the development process by reusing as much code as possible, we chose to implement the apps utilizing a hybrid app technology. A hybrid app is basically a web app running as a native app on mobile devices and can access device features that a pure web app cannot access. The hybrid app frameworks we used to build the HTS@TN apps are Ionic and Capacitor. Ionic offers a standardized toolkit for developing a mobile app user interface while Capacitor brings system features to the web world. With these frameworks, most of the functionality we implemented, including the user interface, REST API communications, and data processing and visualization, are realized by popular web technologies such as TypeScript, React.js and Cascading Style Sheets (CSS). With careful design and implementation, the HTS@TN apps can run seamlessly on different mobile and desktop platforms without the need for platform customization.

The UI of the HTS@TN Android app is depicted in Figure 4-1. The UI of the iOS app is identical. Six different UI screenshots in the figure illustrate different functions. First, once logged in, on the main page, app users can get enrolled into a household travel survey. App users can review, modify, and submit information for the household recruitment survey directly from the app. If the enrollment is approved, a user can begin to record trips daily by choosing the automated trip recording feature powered by on-device location sensors. The trip details will be available for editing once the recording finishes. The user can also choose to enter trip details manually without automated trip tracking. The HTS@TN Android and iOS apps allow users to review past recorded trips and their trajectories if available. Finally, the apps also allow users to review survey summaries and change settings to improve user experience.

There were certain functions that could not be implemented using the web technology stack. For example, to access precise geo-location from the on-device sensors, HTS@TN mobile apps must request the location permission from users and then invoke system APIs to retrieve locations in real time. In addition, the apps need to display a notification to users while tracking, which cannot be done from a pure web app. Therefore, we introduced additional native code to expose these system features to code in the web world via Capacitor plugins. Each plugin implements certain functions that interact with the system and then expose them to the app via JavaScript functions. The plugins are platform-dependent, which means they must be written for both Android and iOS. By doing so, the platform difference between the Android app and the iOS one will not be noticeable, and users will have the same functionality regardless of the device they use.

A number of external services were employed to improve user experience. The most important ones are Google Maps JavaScript API, Places API, and Geocoding API. The Google Maps JavaScript API allows both the mobile apps and the web dashboard to render interactive street maps and display the trajectory of a recorded trip with GPS information. Using the Places API, the apps can provide the address auto-completion feature to users when an address is being entered. The Geocoding API translates geo-coordinates to street addresses so that users can select an address based on the current location instead of entering it manually. Although those third-party services are optional to the core functionality of HTS@TN, i.e., recording trips for a survey, they provide desired user experience and are helpful to increase user participation.

After the HTS@TN server and apps were developed, they were well tested by both the internal project team and external users. The testing spanned several months. During the testing period, the HTS@TN server was deployed in a testing environment at UTC that was separate from but similar to the later production environment, and the mobile apps were released for internal test through a testing channel in the App Store and Google Play. The application was initially tested by the project team members. The testing later was expanded to TDOT staff members as well. Feedback on the application was collected, and certain improvement and optimization were then made to the application based on the feedback. For example, the feature of frequently used addresses was added based on user feedback.

4.2 Results from Pilot HTS Study

4.2.1 Recruitment Survey Results

The pilot HTS study began on April 12 and ended on July 11. During the survey study, recruitment survey submissions were manually reviewed by the project team. If the provided household address in a submission is not in Tennessee or in a neighboring state of Tennessee, or if the address cannot be validated, e.g., no street number or not a household address, the submission will be declined. Each address was manually checked via USPS address validation and/or Google search. Submitted trips were also manually reviewed. One of the reasons for trip manual review is to identify survey participants who will be qualified for a survey reward. Both address and trip manual reviews were time consuming. Some basic statistics of the study are as follows:

- Registered users: 838
- Submitted trips: 3,488
- Submitted households: 735
- Submitted household members: 1,093
- Submitted vehicles: 739
- Approved recruitment survey submissions: 505
- Declined recruitment survey submissions: 406
- Rewarded participants: 223
- Households submitted by rewarded participants: 223
- Members submitted by rewarded participants: 369
- Vehicles submitted by rewarded participants: 232
- Trips submitted by rewarded participants: 1,864

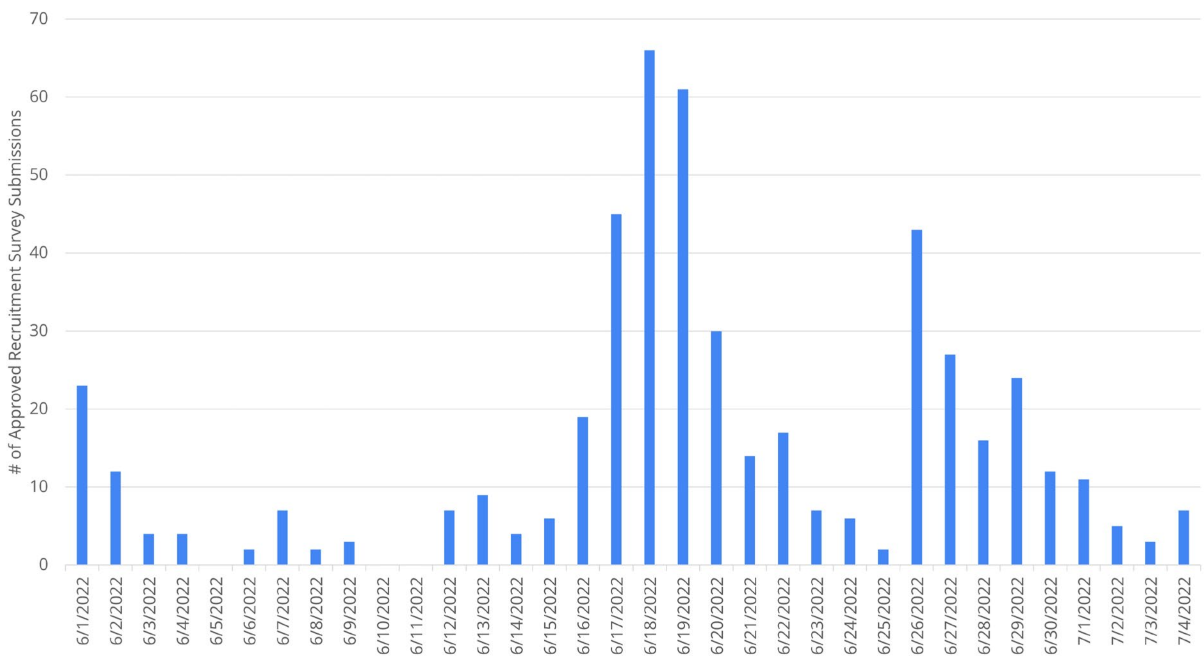

Figure 4-2 Daily Approved Recruitment Survey Submissions (June 1 to July 4)

The majority of the user registrations and recruitment survey submissions occurred after May 31. There were only seven approved recruitment survey submissions prior to June 1, although a number of efforts were spent on survey promotion at UTC. The interview news on June 1 gave a jumpstart to the HTS study. Daily approved recruitment survey submissions, i.e., accepted survey participants, are depicted in Figure 4-2.

There were 406 declined recruitment survey submissions. An interesting observation regarding declined submissions is that certain users repeatedly made submissions with different addresses trying to get approved after their submissions were declined. Some users even changed the state of their household address when they resubmitted their recruitment survey. Our guess is that repeated submissions could be driven by the motive for survey reward.

Survey participants can voluntarily enter a referral code when they sign up on the HTS@TN mobile app. Two referral codes, TN2022 for TN residents and UTC2022 for UTC community, were provided on the survey promotion flyers and advertisements. The use of referral codes during the pilot study is shown in Figure 4-3. As can be seen from the chart, around 28% of all users entered a referral code during account registration. About 23% of the users entered "TN2022" while less than 2% of the users entered "UTC2022".

As not every person who registered an account on HTS@TN or submitted a recruitment survey participated in the pilot study successfully, **the analysis of participant information in the rest of this section focuses on the data provided by those participants who have been given a reward due to their completion of survey**.

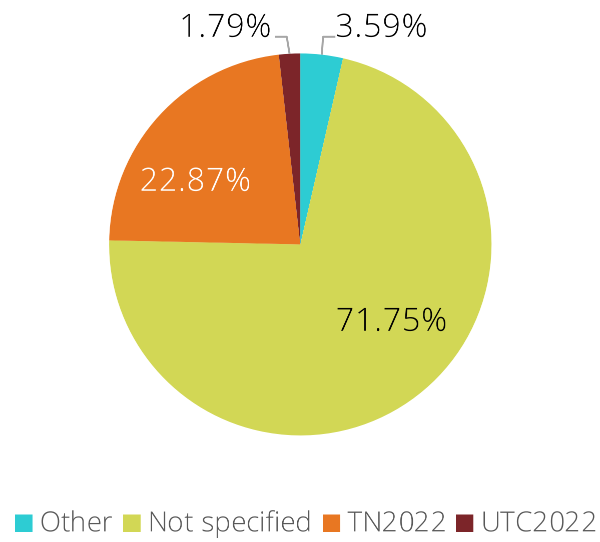

Figure 4-3 User Registration Referral Codes

The recruitment survey data of the rewarded participants provides valuable information about the demographics of the participants and their households. First, the survey data contains the information about geographic location, housing condition, household income, and family size of the participating households. Figure 4-4 illustrates the location of households enrolled in this survey. Most of the households are in the following three counties: Shelby, Davidson, and Hamilton, while others spread across the entire state. This result roughly coincides with the population density of Tennessee in 2020 [35]. Figure 4-5 depicts the housing ownership types and house types of the participants. The data shows that about 73% percent of the households live in rented or leased houses and only 26% of the families live in self-owned houses. Meanwhile, more than 97% of participants choose to live in apartments and houses rather than townhouses and condos. As shown in Figure 4-6, more than half of the participating households were established within the past 5 years, which indicates high household mobility. Finally, Figure 4-7 shows the distribution of annual household income of the participants. According to their self-reported data, the majority of the households have an annual income of $75,000 or more.

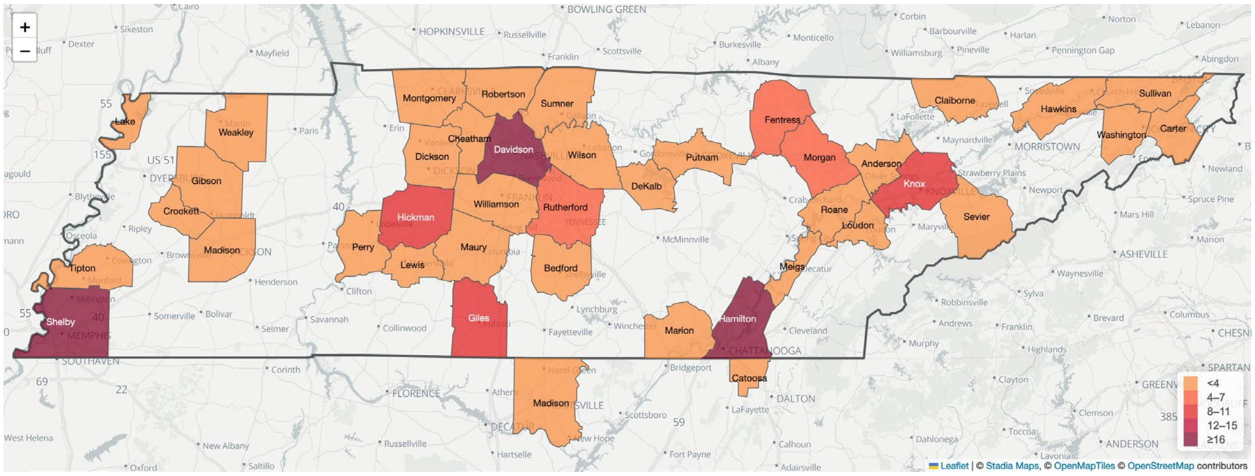

Figure 4-4 Geographic Distribution of Rewarded Households

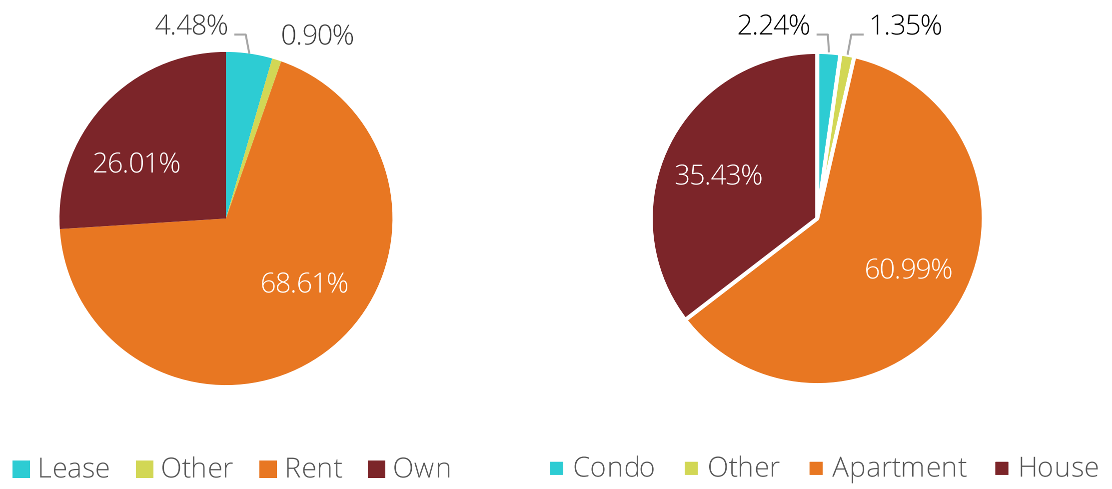

Figure 4-5 Participants' Housing Ownership Types and House Types

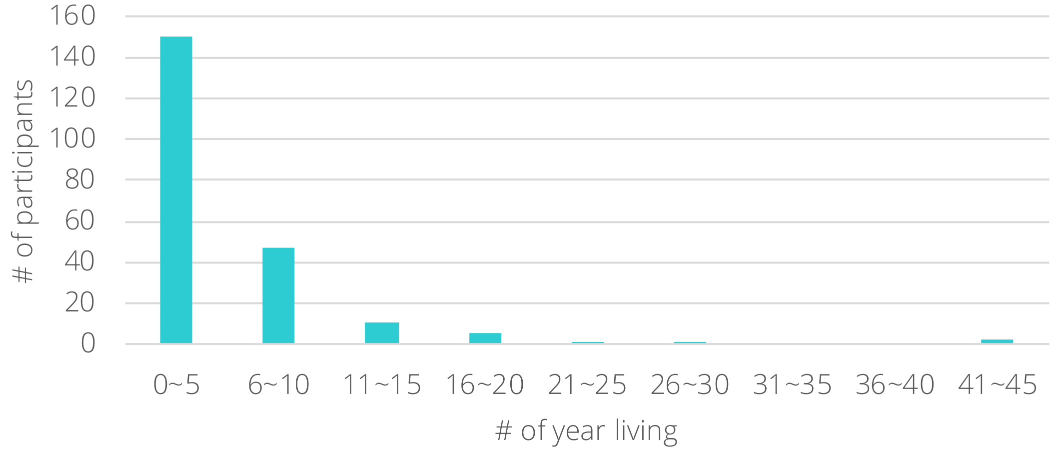

Figure 4-6 Number of Years Rewarded Participants Have Lived in Current Households

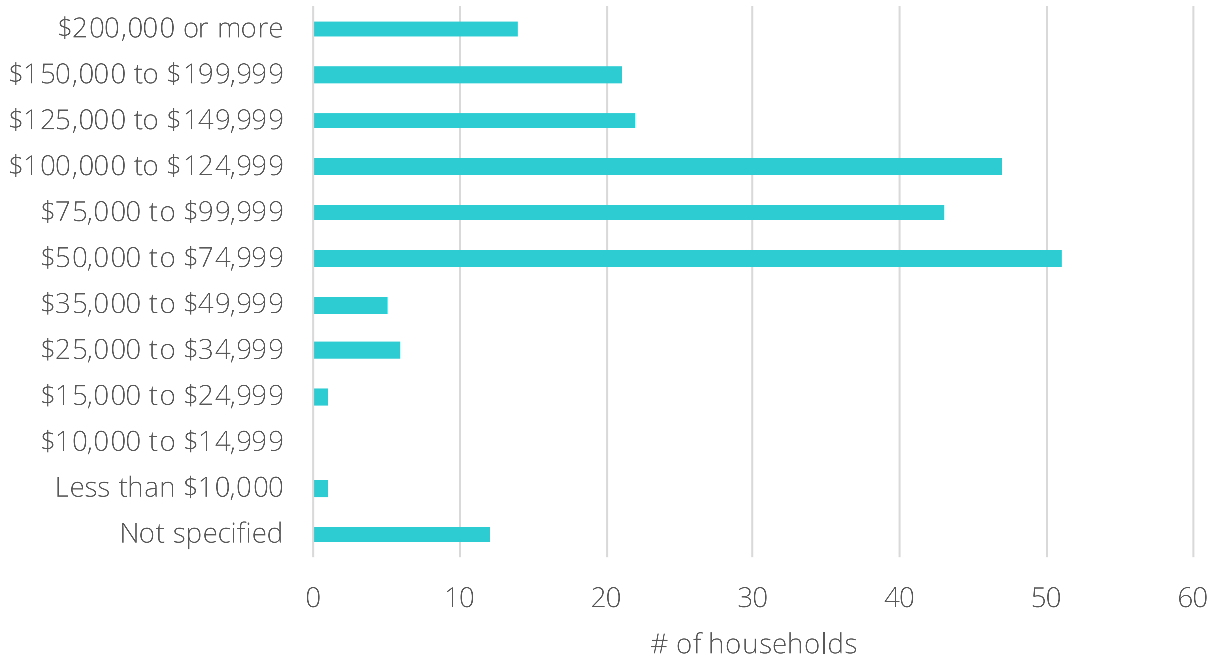

Figure 4-7 Household Annual Income Levels

We further analyzed the demographics of 369 household members whose data was submitted by the rewarded participants. Figure 4-8 shows the age distributions of household owners and all members. The majority of the household members have an age between 10s and 40s are, while most of the household owners are adults between 20 and 50. Regarding the gender distribution of the household members, the data shows that male members are 5.15% more than female members, not counting those who reported as “Other” or “Not specified”, as depicted in Figure 4-9. Note that a nontrivial portion of the participants chose “Not specified” for each of the questions presented in the following.

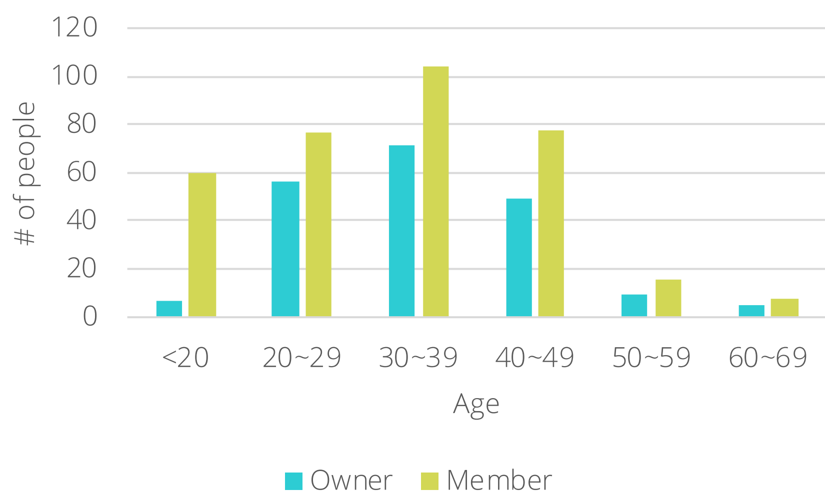

Figure 4-8 Age Distribution of Household Owners and Members

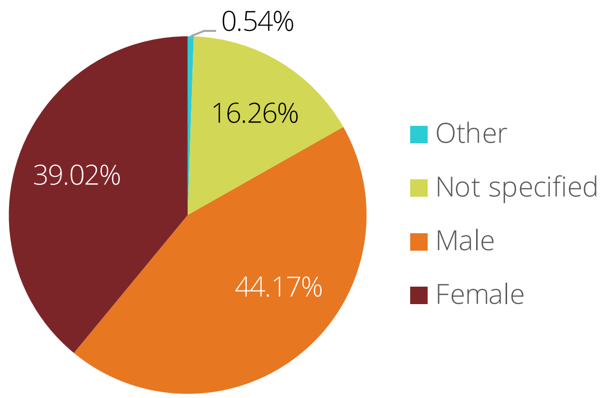

Figure 4-9 Gender Distribution of Household Members

Figure 4-10 depicts the race composition of members of the rewarded households. It shows that most of the household members are white and not Hispanic. Compared with 2020 census data of Tennessee [35], the pilot study results show a smaller percentage of household members in minority racial and ethnic groups.

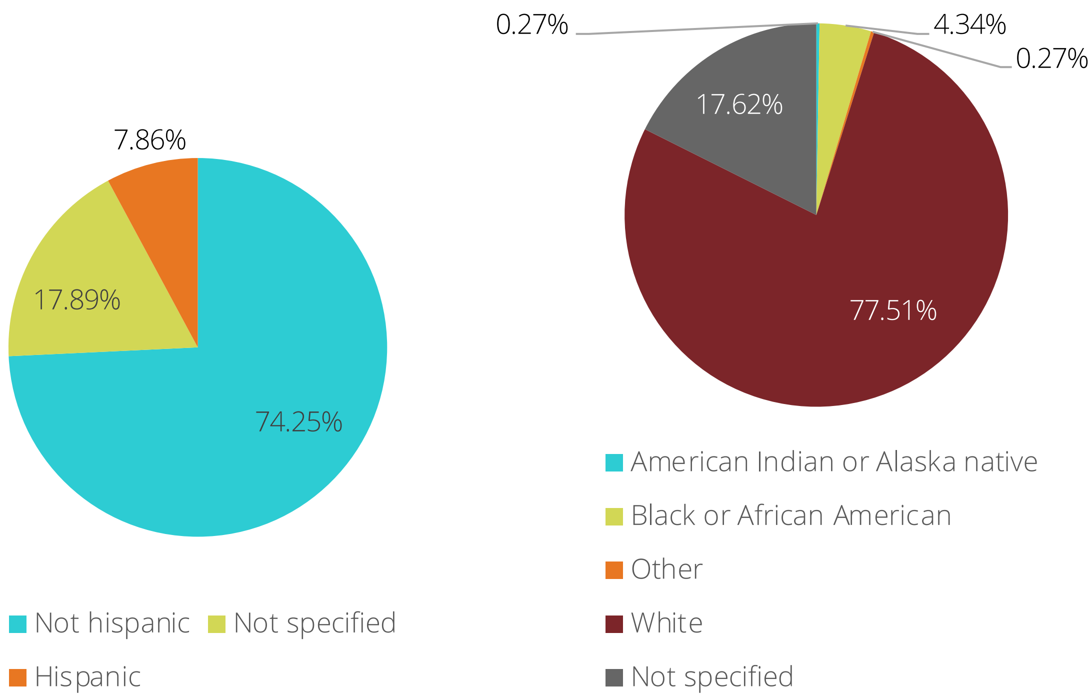

Figure 4-10 Race Composition of Household Members

Figure 4-11 shows the marital status of members of the rewarded households. About 38% of them are married or in a domestic partnership, and about 31% of the people are single and never married. Figure 4-12 and Figure 4-13 display the past and current education of participating household members. More than 68% of the members have a high school or higher degree and about half of the members are currently attending schools or colleges.

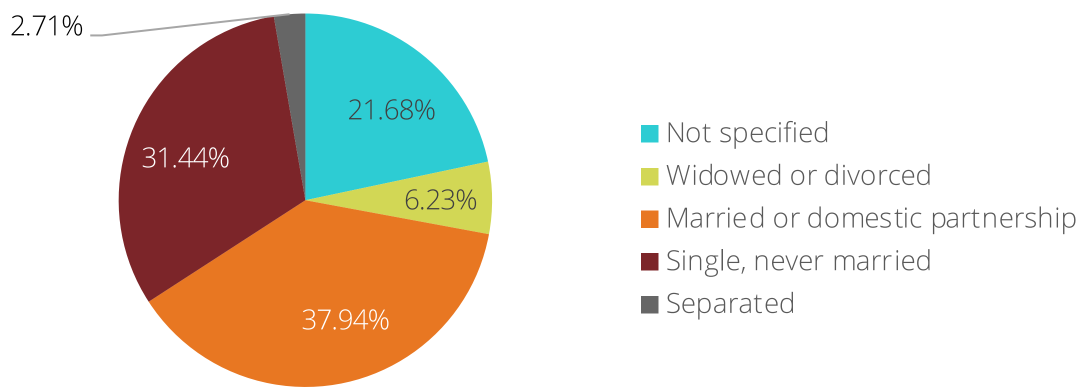

Figure 4-11 Marital Status of Household Members

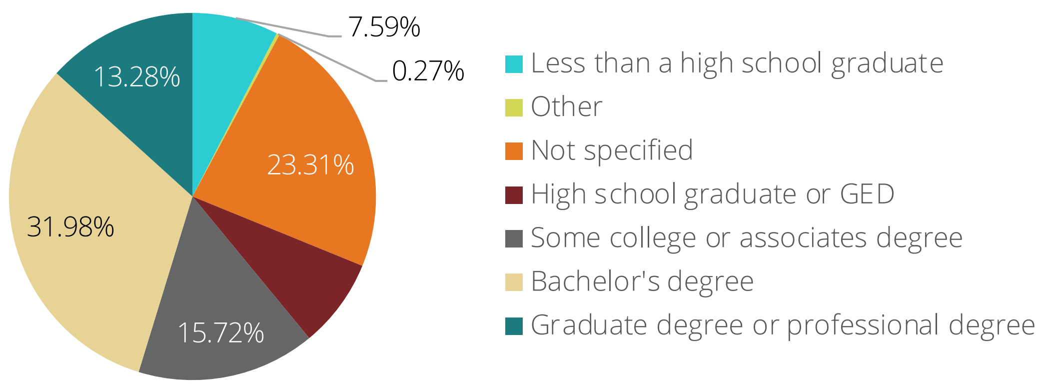

Figure 4-12 Highest Academic Degree of Household Members

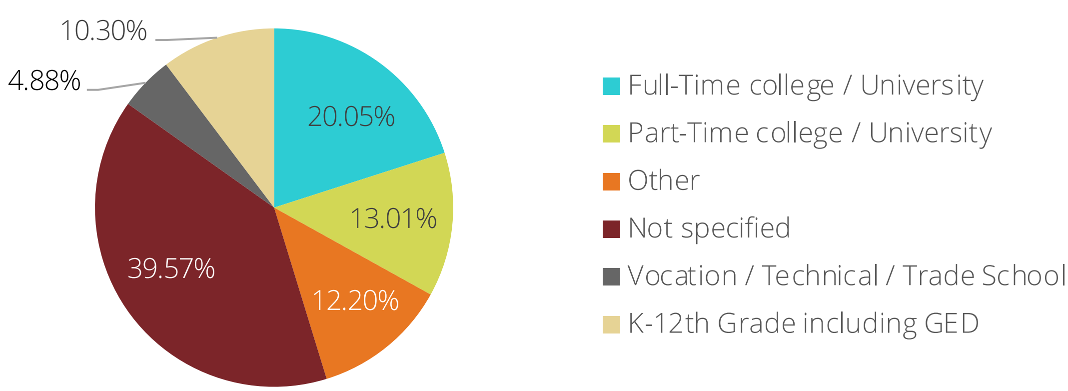

Figure 4-13 Current Level of Education of Household Members

Regarding the employment status of the participating members, Figure 4-14 shows that over 60% of people are employed either full time or part time. Figure 4-15 presents the distribution of primary occupation of the employed members in general categories. The top four occupations are general professionals, service and sales workers, clerical support workers, and managers. 41.73% of the people have one job while 12.47% of them take two or more jobs at the same time, as shown in Figure 4-16.

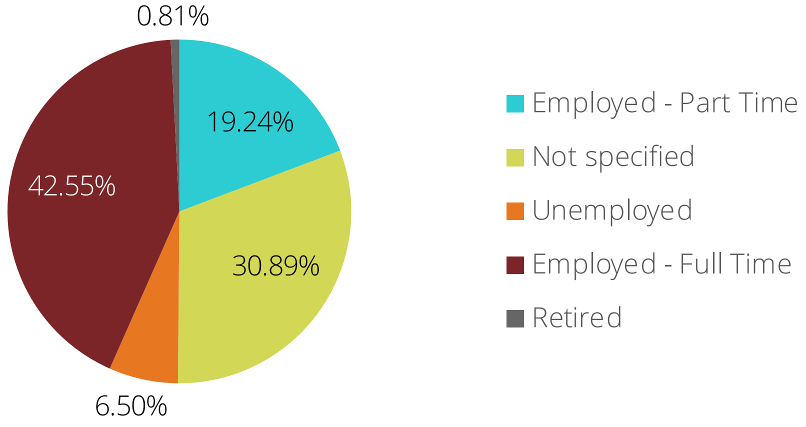

Figure 4-14 Employment Status of Household Members

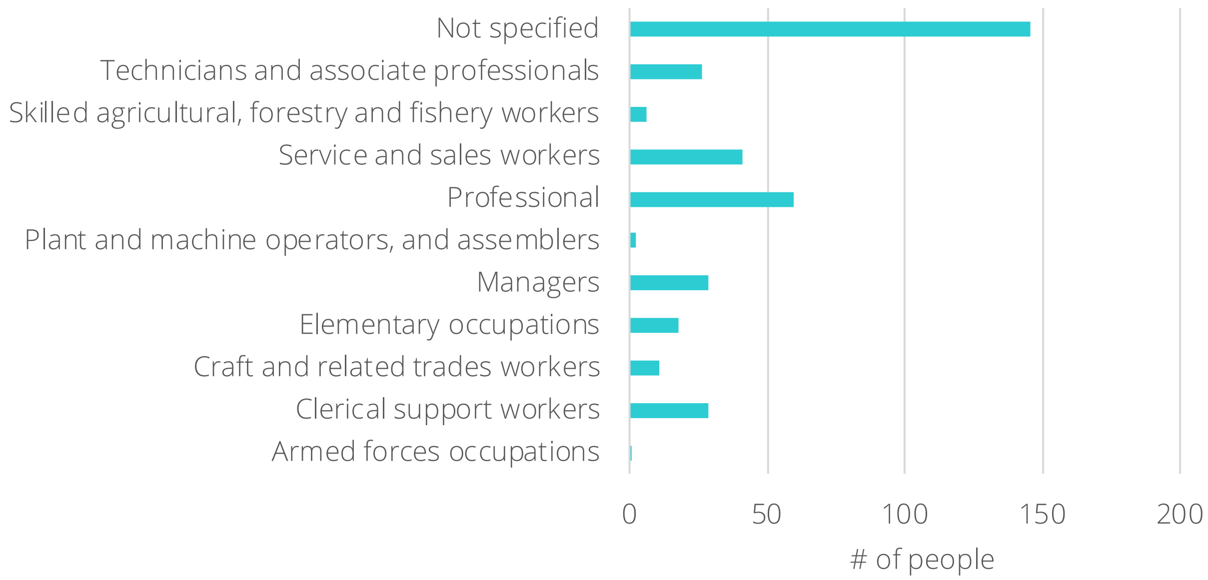

Figure 4-15 Primary Occupation of Household Members

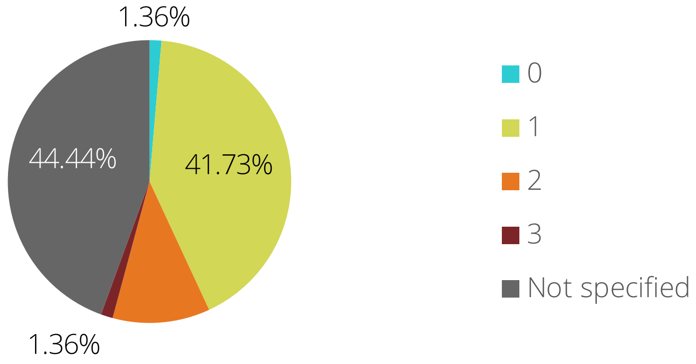

Figure 4-16 Number of Jobs Household Members Have

The survey also asks participants to indicate if household members work for profit, work from home, and if the work is seasonal. The responses are presented in Figure 4-17, Figure 4-18, and Figure 4-19, respectively. According to the self-reported data, 56.64% of the rewarded participants work for profit, 10% of them work from home, and 5.42% of them are seasonal workers. Overall, the survey answers provide a high-level overview of the employment diversity of the rewarded households.

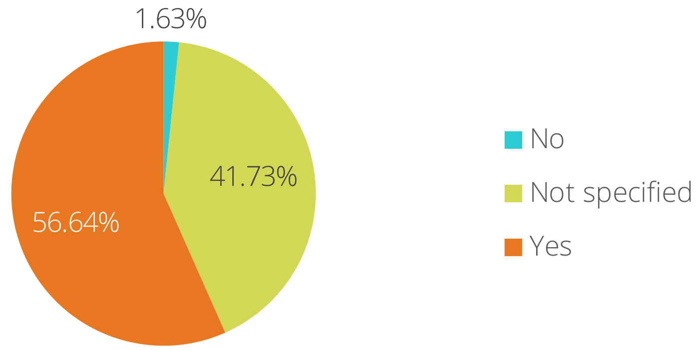

Figure 4-17 If Household Member Works for Profit

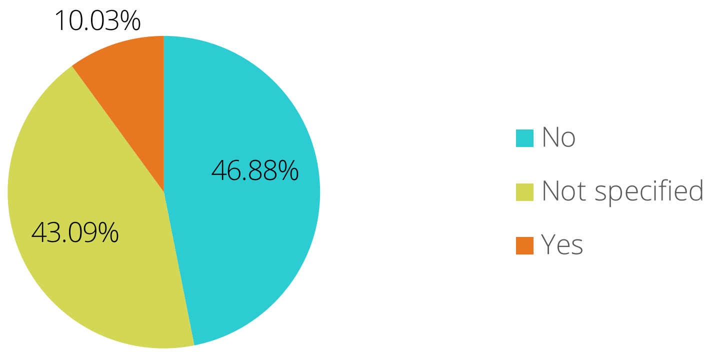

Figure 4-18 If Household Member Works from Home

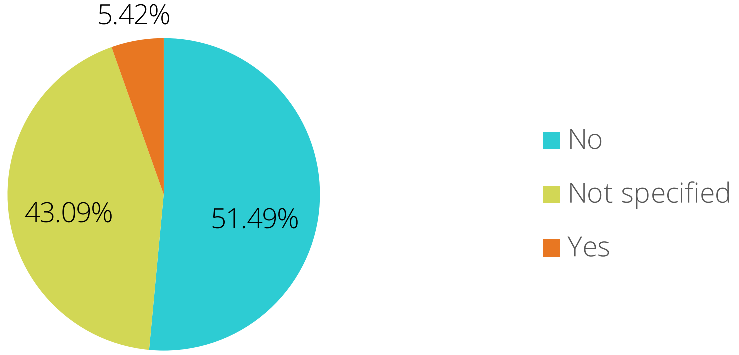

Figure 4-19 If Household Member is a Seasonal Worker

The rewarded participants also submitted information for 232 household vehicles in the survey. Figure 4-20 and Figure 4-21 depict the distribution of year and top 10 brands of those vehicles. Most household vehicles recorded by this survey were produced within the last five years. In addition, the top three brands are Toyota, Ford, and Chevrolet. Regarding types of household vehicle, SUV, car, and pickup truck are the most popular, as shown in Figure 4-22. As for the choice of vehicle color, black, white, grey, and silver are the most popular colors, as indicated in Figure 4-23. Gas is still the primary type of fuel for household vehicles, but alternative type of fuel such as electricity is also emerging according to Figure 4-24. Finally, 13.36% of the vehicles were used vehicles when they were bought, while 55.6% were new vehicles, according to Figure 4-25.

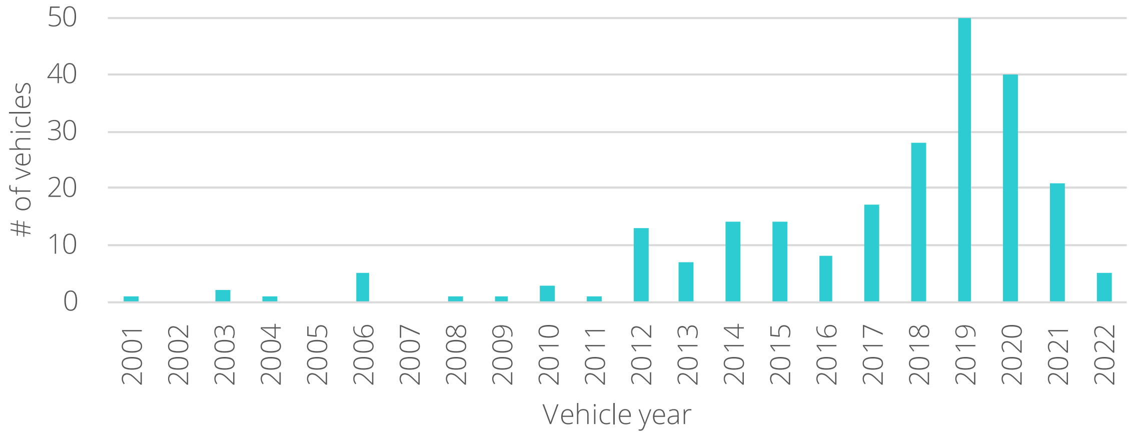

Figure 4-20 Model Year of Vehicles Owned by Rewarded Households

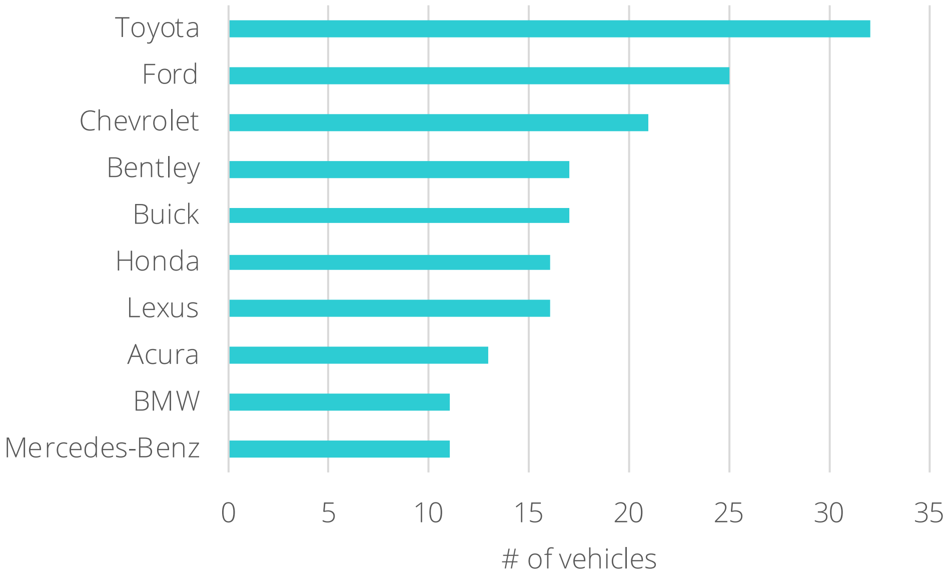

Figure 4-21 Top 10 Brands of Rewarded Household Vehicles

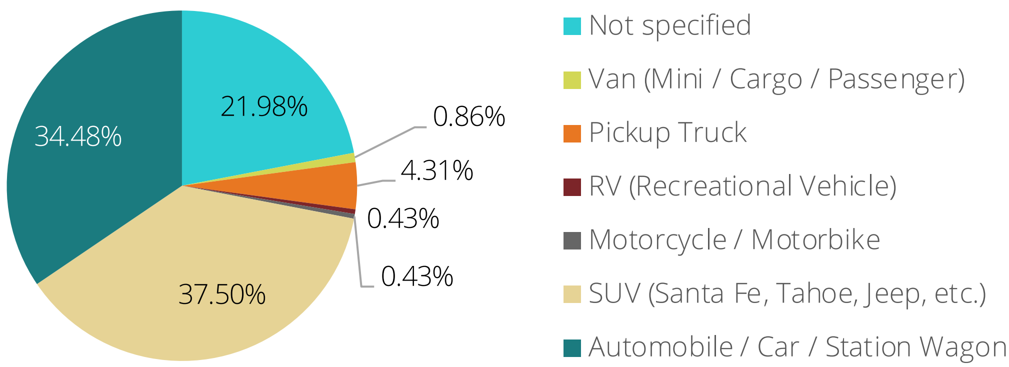

Figure 4-22 Types of Rewarded Household Vehicles

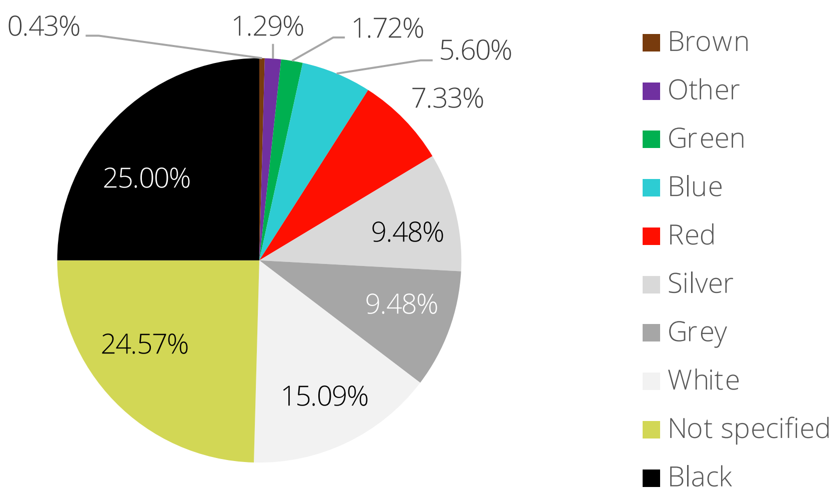

Figure 4-23 Colors of Rewarded Household Vehicles

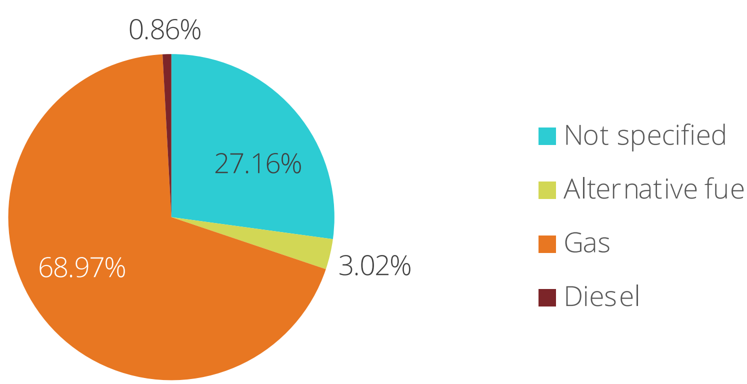

Figure 4-24 Fuel Types of Rewarded Household Vehicles

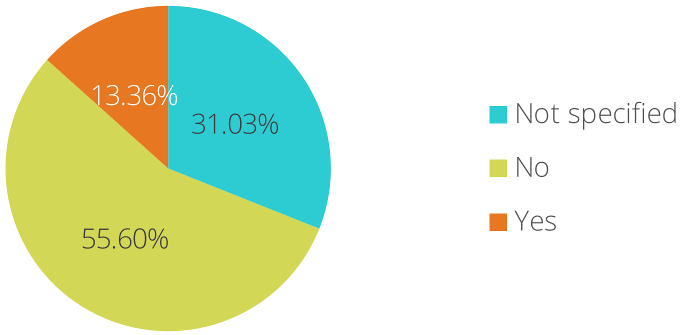

Figure 4-25 If Household Vehicle Was Used When Bought

We also collected the mileage information of household vehicles by asking annual mileage and odometer reading (total mileage) of each vehicle. Figure 4-26 shows that for the vast majority of the household vehicles, their annual mileages are below 50,000, while their total mileages are below 150,000. The overall trend of total mileages is aligned with the fact that most of the vehicles were possessed by the rewarded households in the last five years, as shown in Figure 4-27.

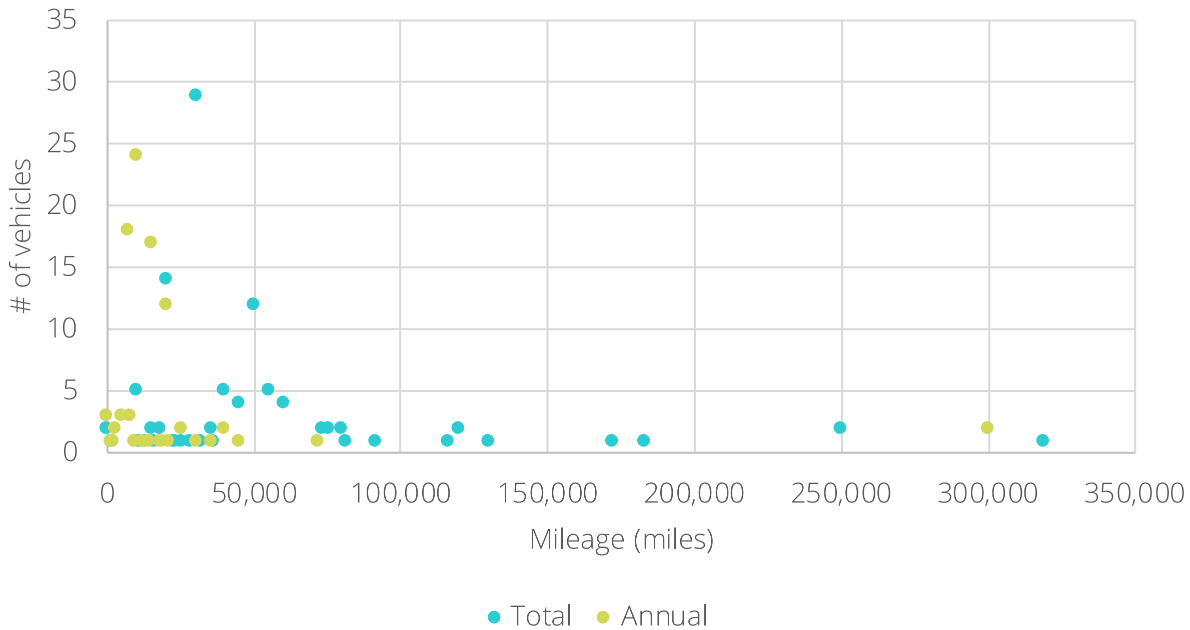

Figure 4-26 Total and Annual Mileages of Household Vehicles

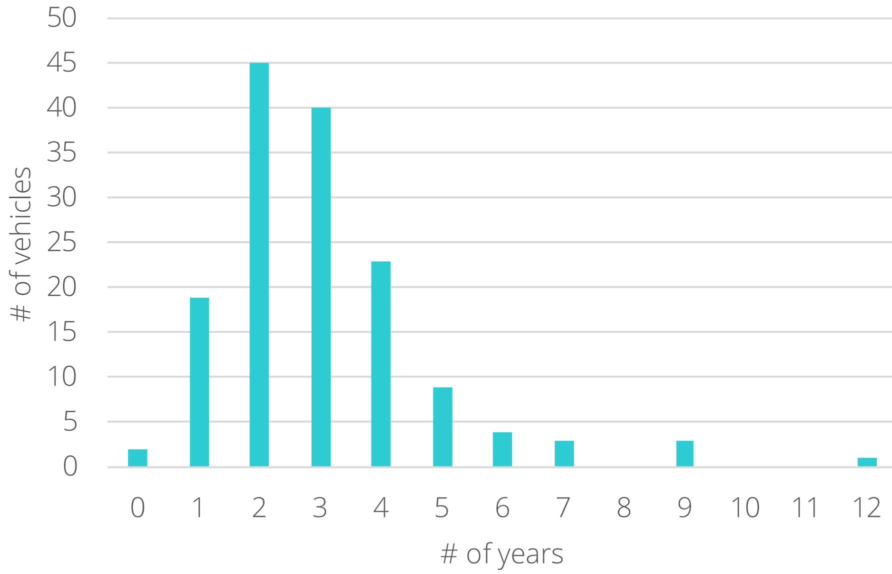

Figure 4-27 Number of Years a Household Vehicle is in Possession

By comparing the age distribution of household members in Figure 4-8 with the age distribution of household drivers in Figure 4-28, a similar pattern of age group distribution is found from both charts. The age groups which most drivers fall in are 30s and 40s, while there are much fewer drivers in 50s and above.

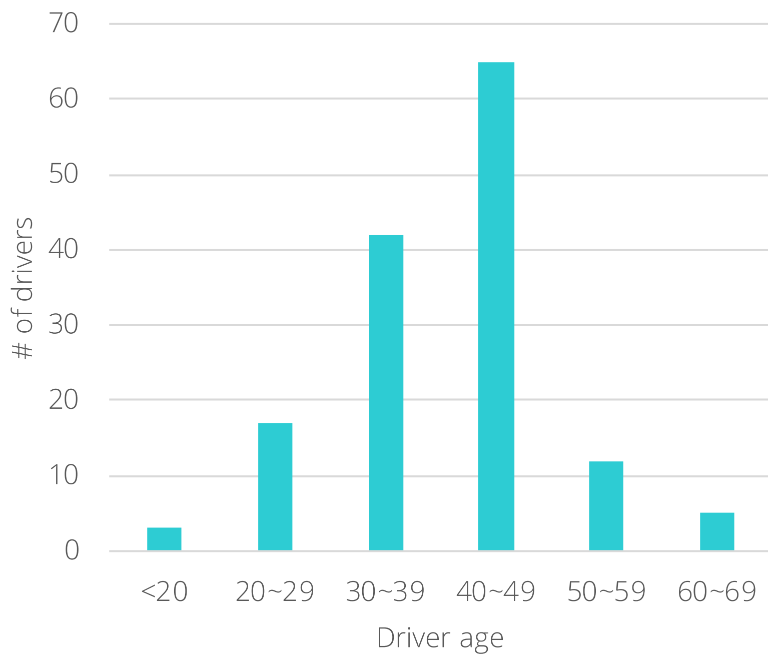

Figure 4-28 Age Distribution of Household Drivers Who Drive a Household Vehicle

4.2.2 Trip Data Analysis

A total of 1,864 trips were submitted by the participants who have been rewarded. Figure 4-29 illustrates the number of trips started and ended in each day from April 19 to July 10. The results show that the majority of trips were submitted after June 1, which is well aligned with the fact that most of the participants were accepted after that date. There are minor differences between the numbers of started trips and those of ended trips as some trips span more than one day.

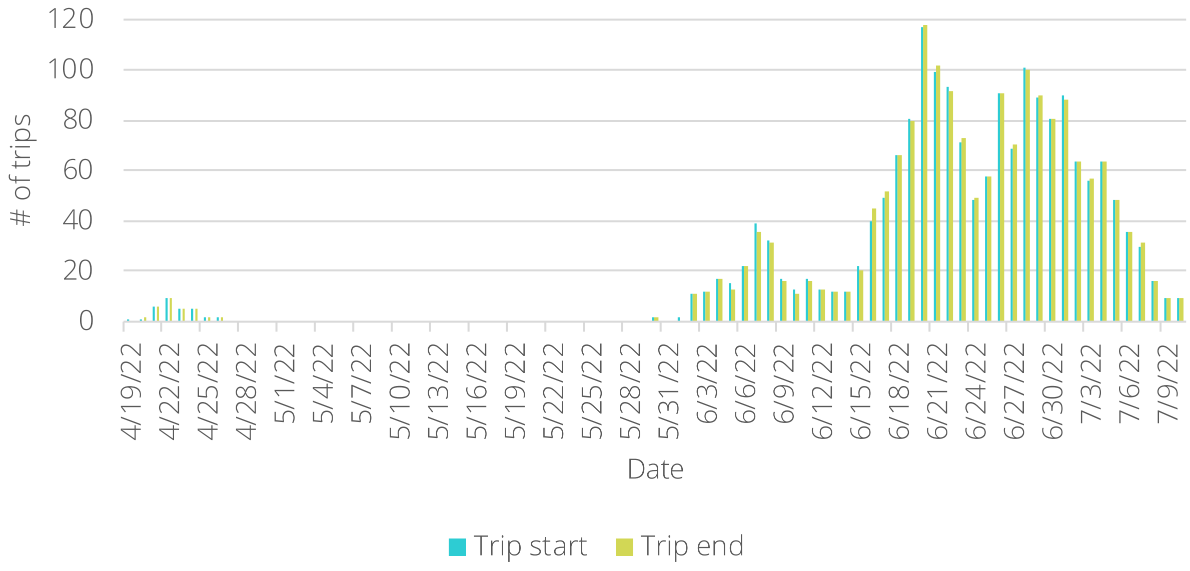

Figure 4-29 Daily Trips Submitted by Rewarded Participants (April 19 to July 10)

Figure 4-30 and Figure 4-31 depict the geographic information of trip start locations (in county) and destination locations, respectively. The distribution of trips correlates to the distribution of households shown in Figure 4-4. TABLE I lists trip purposes and their corresponding percentages. More than 60% of the trips are related to daily life, such as going to work, going home, or buying goods or meals. Those activities usually take place not far from household locations, which helps explain the correlation between the distribution of trips and that of households.

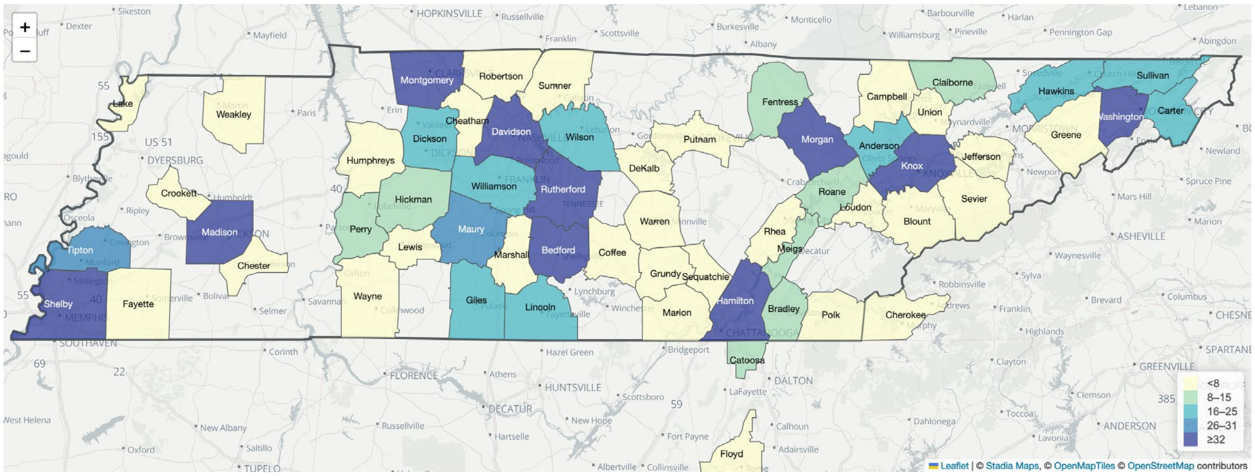

Figure 4-30 Geographic Distribution of Trip Start Counties

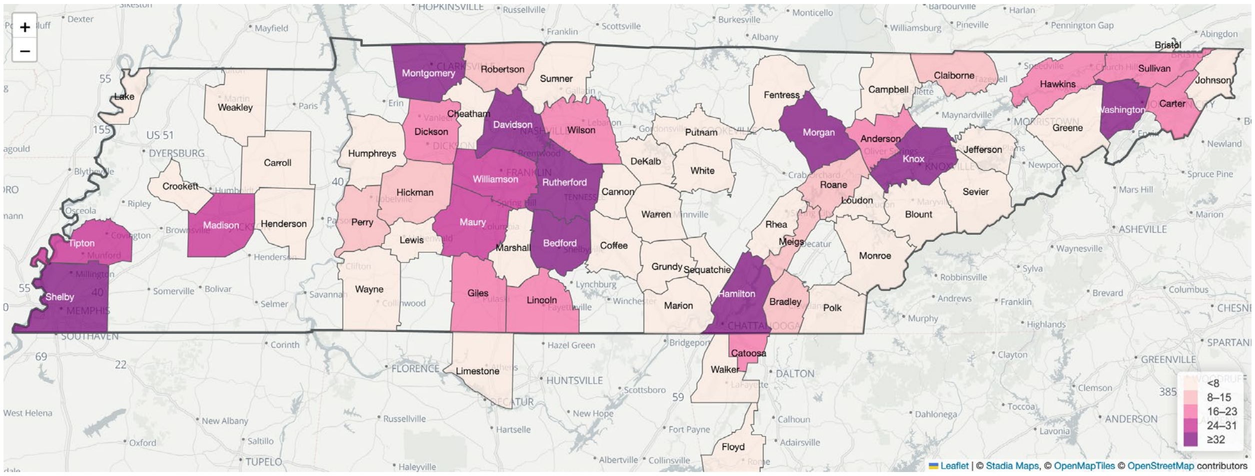

Figure 4-31 Geographic Distribution of Trip Destination Counties

TABLE I TRIP PURPOSES LABELED BY PARTICIPANTS

Trip purpose	Percentage of trips (%)
Go home	20.87
Work	16.68
Buy goods (groceries, clothes, appliances, gas)	9.07
Buy meals (go out for a meal, snack, carry-out)	7.24
Drop off/pick up someone	5.95
Work-related meeting/trip	5.63
Religious or other community activities	5.63
Visit friends or relatives	4.83
Recreational activities (visit parks, movies, bars, museums)	4.45
Exercise (go for a jog, walk, walk the dog, go to the gym)	4.08
Buy services (dry cleaners, banking, service a car, pet care)	3.97
Attend school as a student	2.84
Health care visit (medical, dental, therapy)	2.63
Other general errands (post office, library)	1.77
Other	1.56
Change type of transportation	1.02

Volunteer activities (not paid)	0.97
Attend adult care	0.43
Attend child care	0.38

TABLE II presents popular trip transportation methods labeled by the participants. More than 77% of the trips were taken by personal vehicles such as cars, SUVs, and pickup trucks. The result also indicates a good percentage of ride-sharing trips (~10%). In comparison, trips served by public transportation are much less (< 3%).

TABLE II TRIP TRANSPORTATION MODE LABELED BY PARTICIPANTS

Transportation mode	Percentage of trips (%)
Car	57.30
SUV	18.19
Taxi / Limo (including Uber / Lyft)	10.46
Walk	5.90
Pickup truck	2.25
Public or commuter bus	1.93
Bicycle	1.61
Motorcycle / Moped / Scooter	1.13
Rental car (including Zipcar / Car2Go)	0.27
Private / Charter / Tour / Shuttle bus	0.27
Golf cart / Segway	0.21
Van	0.21
School bus	0.16
City-to-city bus (Greyhound, Megabus)	0.11

Figure 4-32 shows the distances of the trips. It is clear that most of the trips are shorter than 20 miles. About 63% of the trips are under 10 miles and 80% of the trips are under 20 miles. There are only 3.7% of the trips are above 100 miles.

The distribution of party size of the trips is presented in Figure 4-33. 79.23% of the trips were made by the participants alone.

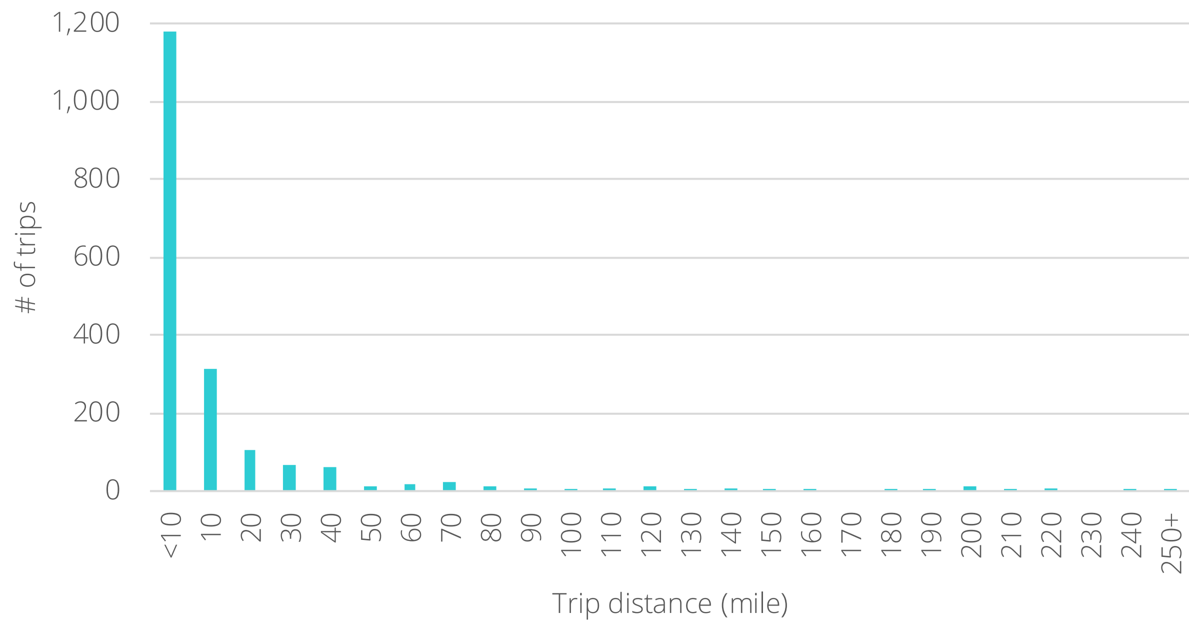

Figure 4-32 Distances of Trips Submitted by Rewarded Participants

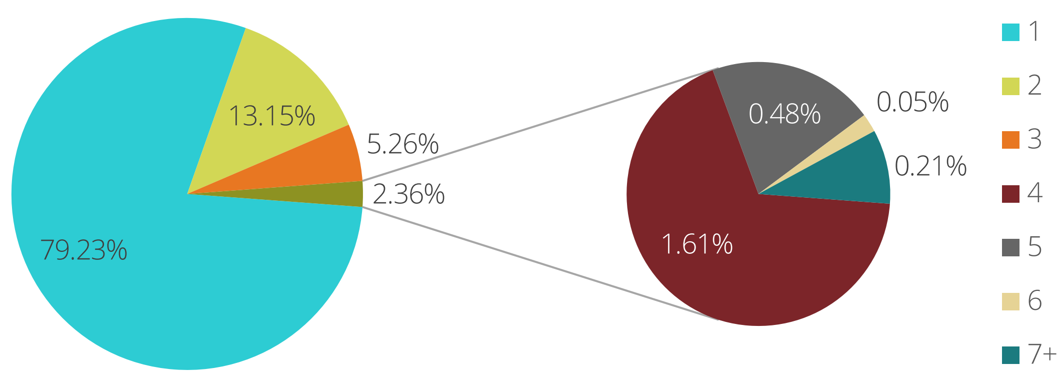

Figure 4-33 Party Sizes of Trips Submitted by Rewarded Participants

Finally, as the HTS@TN mobile app has GPS tracking function, some participants chose to record GPS coordinates of their trips using the app. A total of 369 trips were recorded using the GPS tracking method, which amounts to 19.8% of all the trips counted. Figure 4-35 depicts the aggregated GPS coordinates of those trips on the map. The numbers in the orange and yellow circles indicate the numbers of coordinates appeared nearby. The larger the number is, the more GPS coordinates were collected in the neighboring area. The result shows that most of the GPS coordinates were collected in Chattanooga, Knoxville, Nashville, and Memphis downtown areas as well as the connecting highways. The collected coordinates also contain time information, which can be used to replay trip trajectories and analyze road usage. However, this type of analysis is out of the scope of this study.

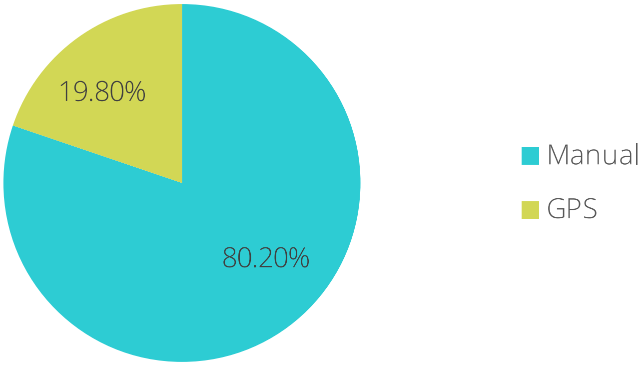

Figure 4-34 Trip Recording Methods

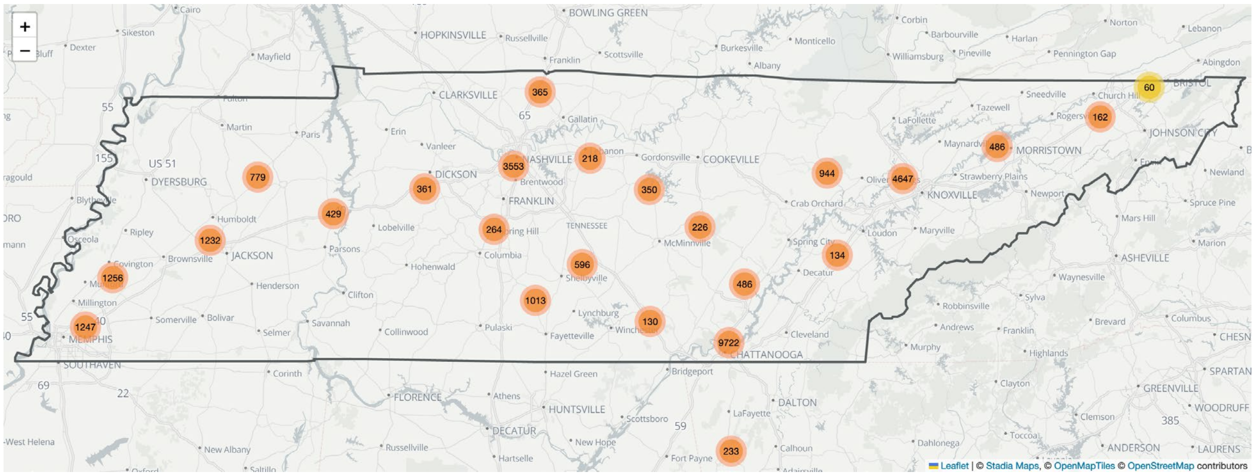

Figure 4-35 Geographic Distribution of Recorded Trip GPS Coordinates

4.2.3 Statistics of Google APIs

The HTS@TN server ran well without any problem during the survey study, even when the number of participants grew substantially in June. The load on the server did not appear high.

Since Google APIs used in the HTS@TN apps are paid services[2], it is interesting to examine the usage of Google APIs. As mentioned before, three APIs: Maps JavaScript API, Places API, and Geocoding API were used in the apps. The daily traffic (number of calls) of the three Google APIs is depicted in Figure 4-36. We can see that the usage of the Maps JavaScript API was fairly low across the study while the usage of the Places API, which is invoked for address auto-completion, exhibited high spikes that appear correlated with the dynamics of accepted survey participants. Corresponding spikes also manifested in the usage of the Geocoding API but they were much less vibrant. The usage of the three APIs was covered by the free credits (approximately $130 in cash value) given by Google during the study.

[2] Google APIs provide free credits and charge for usage after the credits are used up.

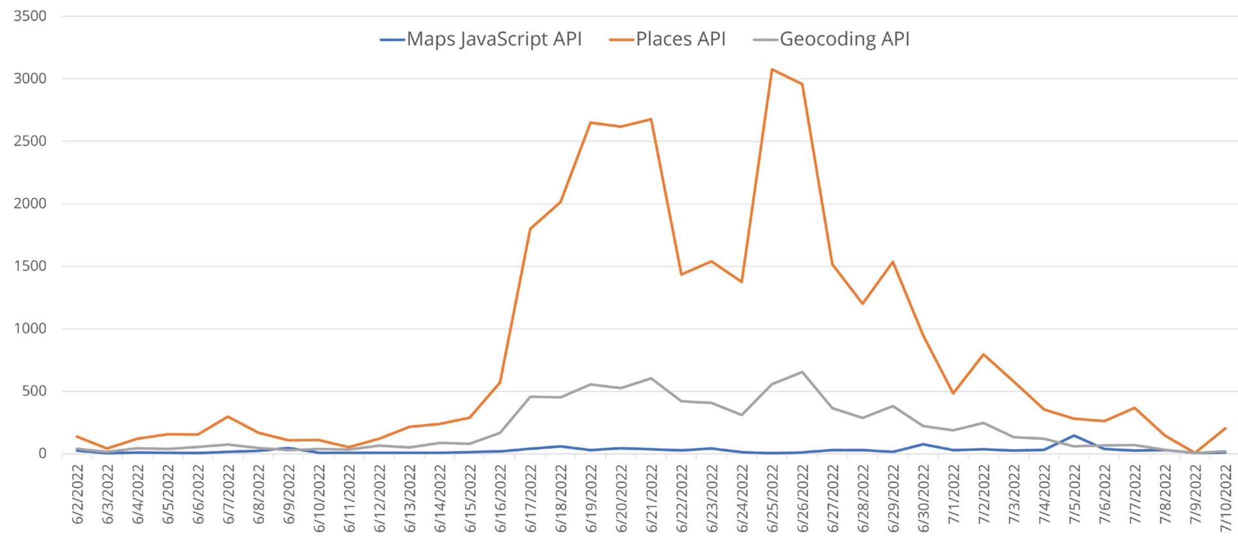

Figure 4-36 Daily Traffic of Used Google APIs

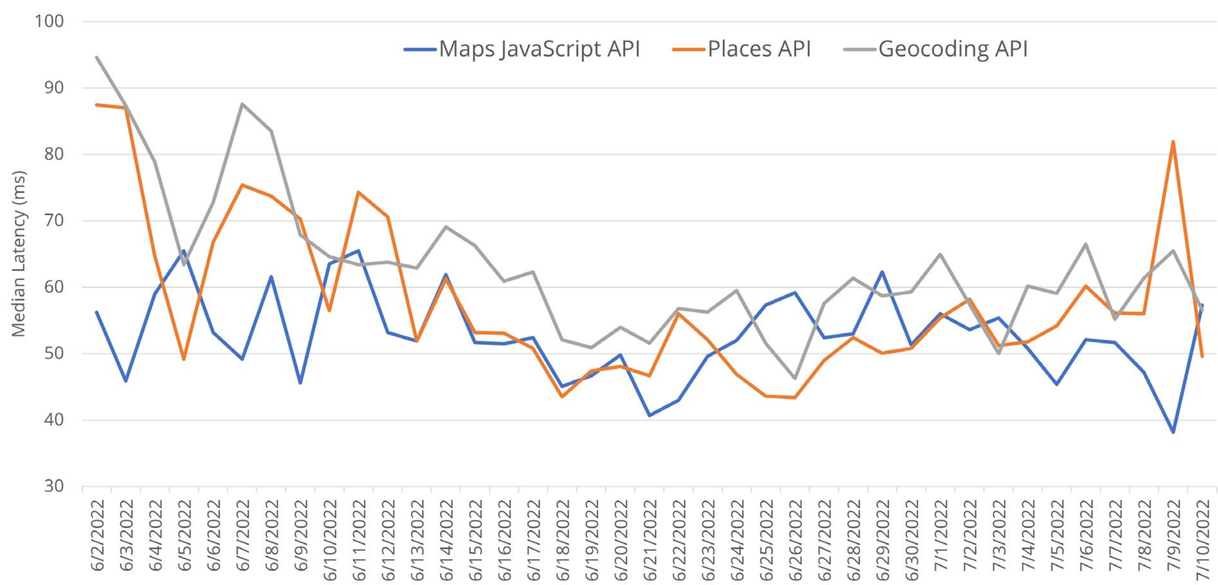

Figure 4-37 Median Latency of Used Google APIs

Latency of the Google APIs can affect user experience of the mobile apps. The smaller the latency of a Google API is, the better the user experience will be. Daily median latency values for the three Google APIs are illustrated in Figure 4-37. We can clearly see that all the median latencies were small and that they were less than 70ms most of the time. It is also worth noting that all the API calls had a success response code. The low latency attained in the pilot study is not only a clear indicator of good performance of the HTS@TN application but also a positive factor to its user experience and app feedback, which is presented in the next section.

4.2.4 App User Feedback

The HTS@TN mobile apps have a built-in user feedback survey that contains six questions about the app. The first five questions ask users to rate the app's overall experience, functionality, usability, stability, and its look & feel with a scale from 1 to 5, the higher the better. The last question is optional and open-ended, seeking user's comments on how to improve the app. The full list of the questions is provided in Appendix C.

Thirty five (35) survey participants submitted their feedback through their app during the pilot survey study. The mean and standard deviation values of the ratings for the first five scale questions are shown in TABLE III. It is clear that the average ratings for four individual categories and overall experience are all above 4 with the scale range from 1 to 5, suggesting that the survey participants were quite satisfied with the mobile apps.

Although not required, 13 participants still commented the mobile apps through question 6. Among them, ten comments are positive about the apps. They are listed as follows:

1. "I love everything about this app"
2. "What an amazing app, can't even figure out what to improve in this app"
3. "It was actually a wonderful experience"
4. "Great app"
5. "It was fun using this app, i love it"
6. "I think it's presently okay and in a good shape"
7. "Nice app" (the same comment made by two different participants)
8. "It's good like that"
9. "The app is okay"

Three participants shared their opinion about where the apps could be improved. Their comments are follows:

- "Locations are as not exact as desired"
- "I feel there's need for notification pop up"
- "The look needs more catchy designs"

TABLE III PARTICIPANTS' APP FEEDBACK RATINGS (SCALE RANGE: 1-5, 5 IS BEST)

	Mean of the Ratings	*Standard Deviation of the Ratings*
Functionality	4.43	0.61
Usability	4.34	0.68
Stability	4.66	0.54
Look & Feel	4.20	0.83
Overall	4.29	0.62

The feedback indicates that the HTS@TN mobile apps in general functioned well with good usability and stability and acceptable user interface during the pilot HTS study. Although certain aspects and functions can be improved, the overall user experience is positive.

4.2.5 Results from Social Media Advertisements

To attract more people to participate in the pilot survey, a total of five social media advertisements (with notations Ad 1 - Ad 5) were made on Facebook and Instagram using two different strategies. For each of the advertisements, one or more graphical posts for recruitment for the pilot survey were published on Facebook and Instagram through the "Ad Center" function on Facebook.

When an online advertisement (or ad) is created, different promotion strategies are available to select for the ad. Two different strategies were tried as there were no prior experiences or best practices for the research team to follow. Strategy one (S1) aims to get more engagements for the ad posts, while strategy two (S2) aims to get more link clicks for the posts. According to Facebook, ads with Strategy S1 would target users who are likely to react upon, comment on, and/or share the ads, while ads with Strategy S2 would target users who are likely to click a web link in the ads. The result of ads with Strategy S1 is measured by the number of post engagements while the result of ads with Strategy S2 is measured by the number of link clicks. Strategy S1 was used for the first two advertisements (Ad 1 and Ad 2), while Strategy S2 was used for the rest advertisements (Ad 3, Ad 4, and Ad 5).

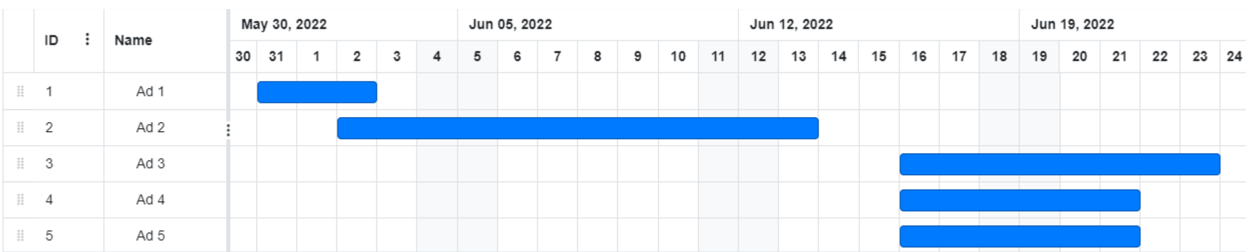

Figure 4-38 Timeline of Advertisements

The timelines of the five ads are shown in Figure 4-38. Ad 1 was a feasibility test of online promotion for the survey study. Ad 2 was basically the same as Ad 1 but ran for a much longer time to get baseline data. Based on the analysis of the data from Ad 2, three new ads with different graphical designs and targeted user groups were created and launched using a different strategy, i.e., S2. More specifically, Ad 3 was set to target female users, Ad 4 to male users, and Ad 5 to both male and female users, all in the age range 18-44.

On Facebook, the amount of "reach" for an ad refers to the number of users who viewed the ad at least once. Figure 4-39 shows the numbers of reach by gender for each of the five ads. Clearly, Ads 3 and 4 reached significantly more users than Ad 2, although Ad 3 only reached female users and Ad 4 only reached male users. In addition, Ad 5 reached both male and female users with more female users than male users, and the total reach number for Ad 5 is at the same level as that for Ad 2. The observations from Figure 4-39 suggest effective advertisements consider the gender difference.

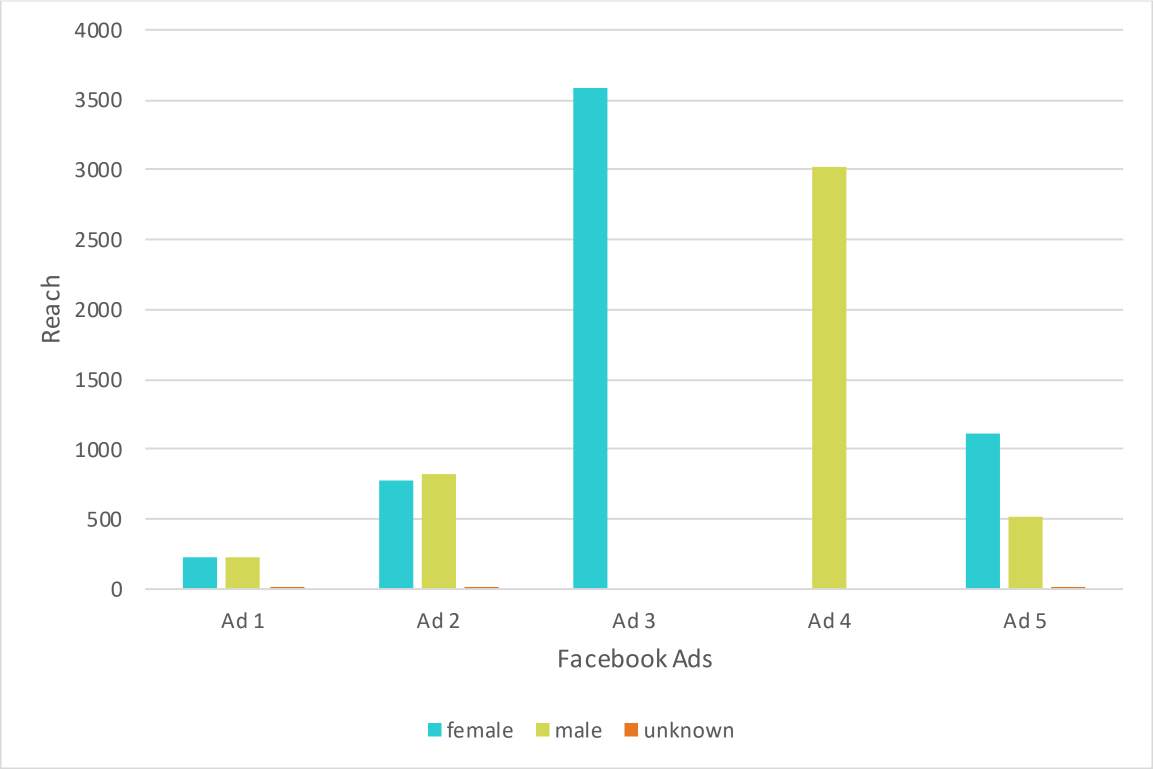

Figure 4-39 Reach by Gender for Each Ad

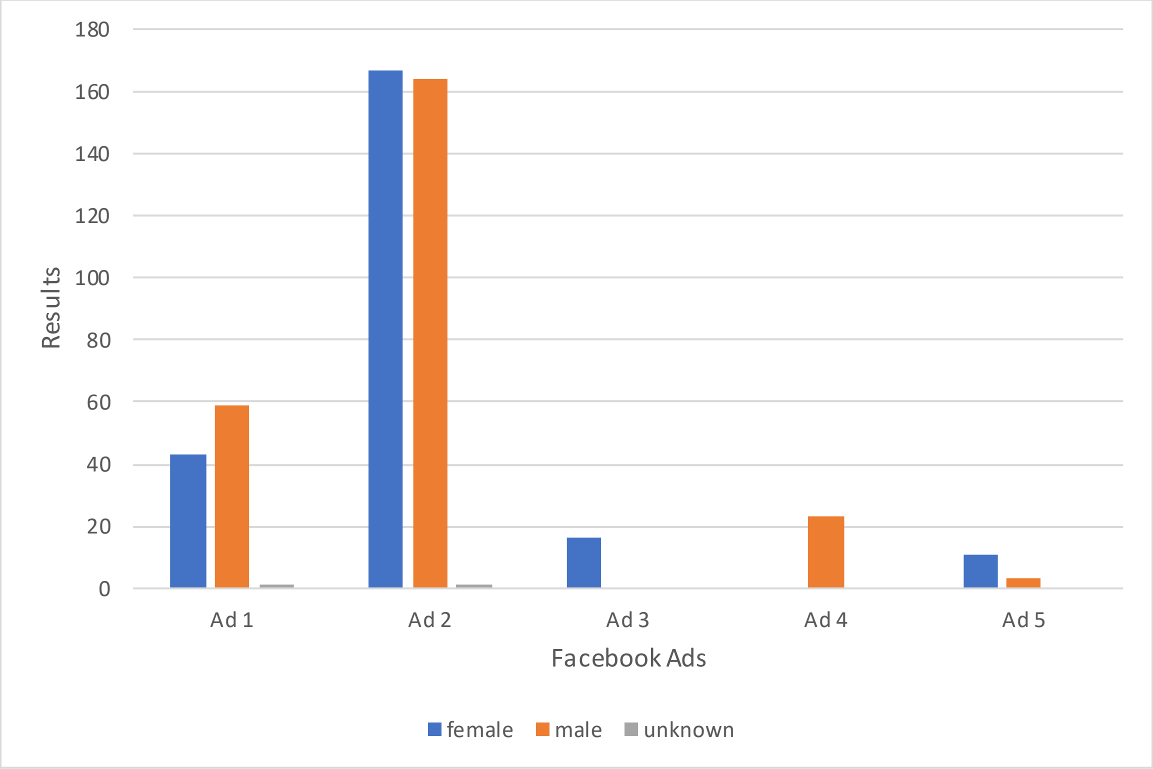

Figure 4-40 Result by Gender for Each Ad
(Engagements for Ads 1-2 & Link Clicks for Ads 3-5)

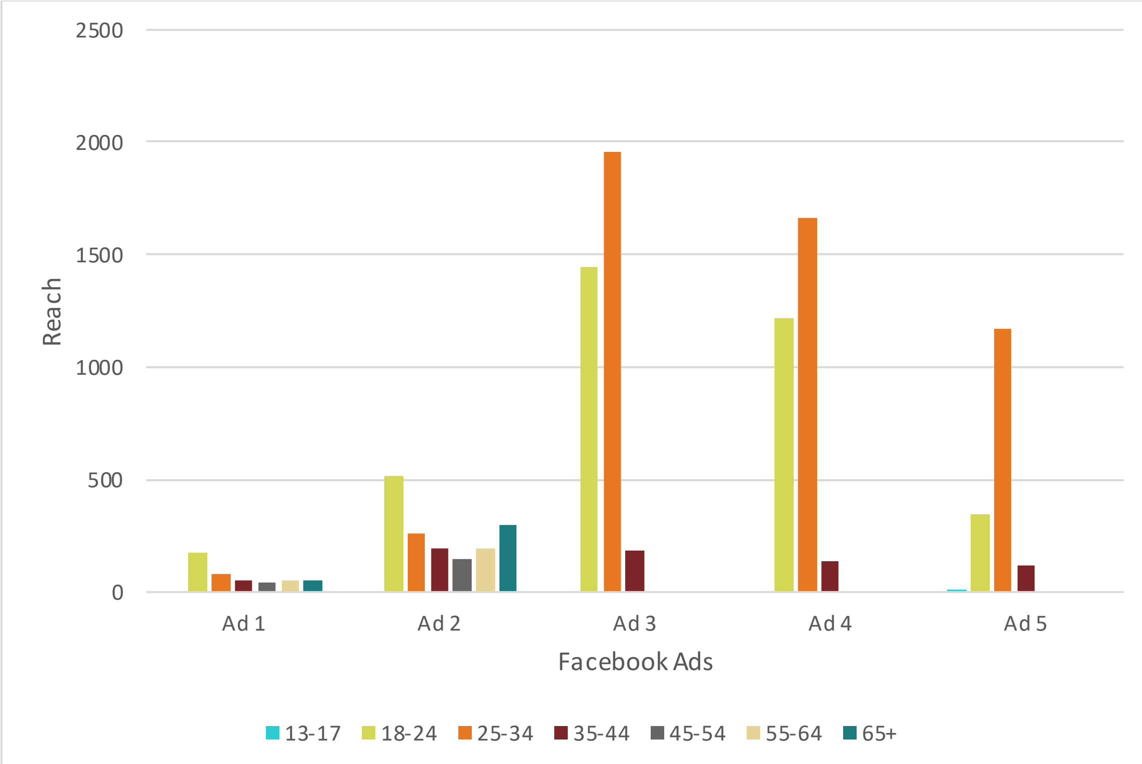

Figure 4-41 Reach by Age Group for Each Ad

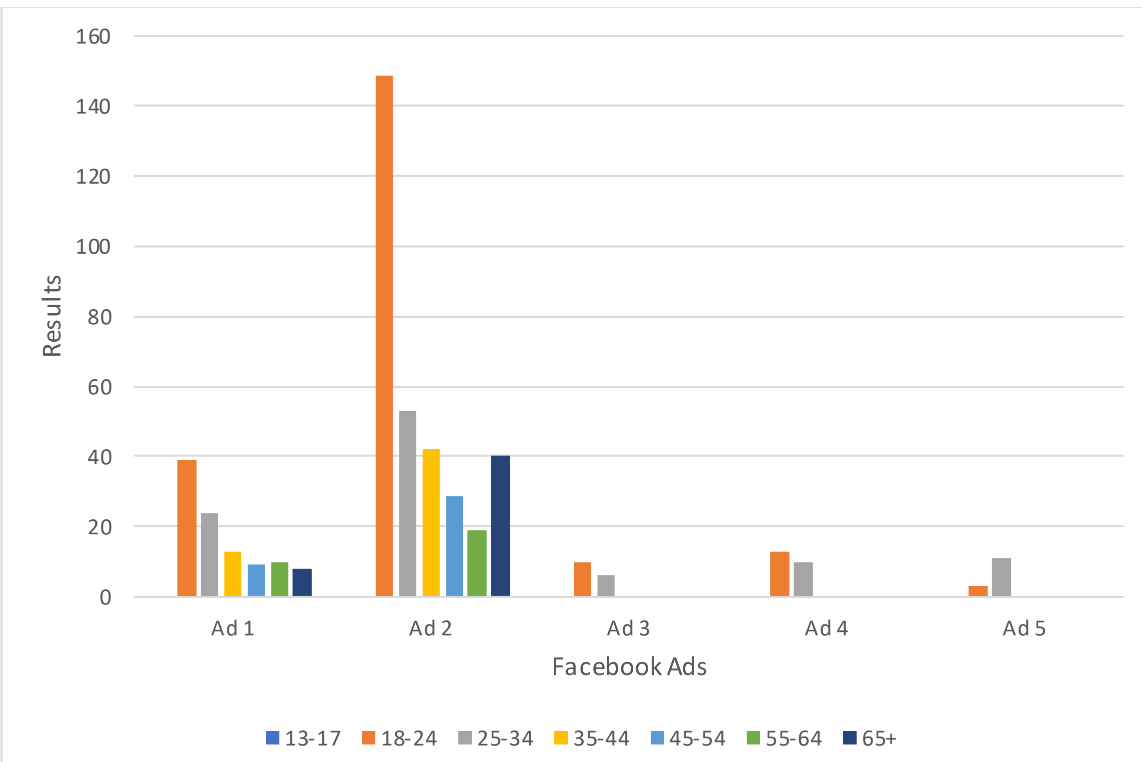

Figure 4-42 Result by Age Group for Each Ad (Engagements for Ads 1-2 & Link Clicks for Ads 3-5)

Figure 4-40 shows the results for the five ads. The "Result" of Ads 1-2 refers to the number of engagements while the "Result" of Ads 3-5 refers to link clicks. It can be seen that not many users clicked the link of the study website in Ads 3-5. However, a drastic increase of submitted (and approved) recruitment surveys happened during the time period of Ads 3-5, as shown in Figure 4-2. In contrast, although the engagement numbers for Ads 1-2 appear much higher than the numbers of link clicks for Ads 3-5, the numbers of approved recruitment surveys during the time period of Ads 1-2 are pretty low. The high spike occurred on June 1 and 2 is more likely caused by the local TV news about the survey study, instead of by Ads 1-2.

Ads 1-2 targeted all Tennessee users over 18. However, the Reach and Result data from Ads 1-2 reveal that different age groups react on the ads differently. As shown in Figure 4-41 and Figure 4-42, users in the age range 18-24 have the highest reach and engagement numbers in Ads 1-2. Consequently, Ads 3-5 were set to target users in the age range 18-44. From Figure 4-41 and Figure 4-42, it appears that users in the age range 18-34 are much more active in terms of reach and link clicks and that the adjustment of target user group for Ads 3-5 is effective.

To understand the cost-effectiveness of online promotion, Figure 4-43 shows the number of users an ad has reached and the cost of the ad, i.e., dollar amount spent, for each of the five ads. Clearly, in terms of the number of users reached per dollar, Ads 3-5 are much more cost-effective than Ads 1-2 as they reached way more people.

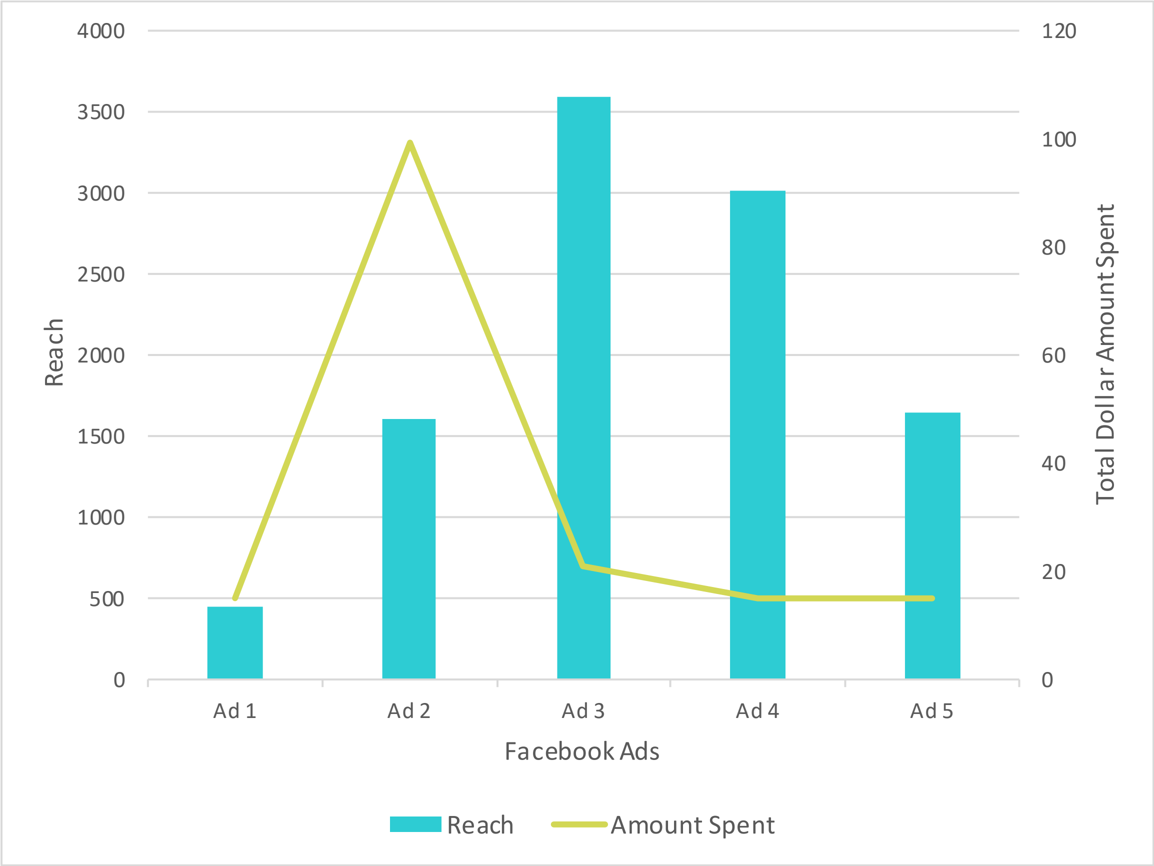

Figure 4-43 Reach and Cost for Each Ad

Figure 4-44 illustrates daily numbers of users reached by the ads and daily numbers of accepted participants from 05/31/22 to 06/23/22. As the durations of Ads 3-5 overlap, the "Reach" numbers for Ads 3-5 stack together. It can be seen that a correlation appears between the total number of ad Reach and the number of accepted survey participants during 6/16 to 6/22.

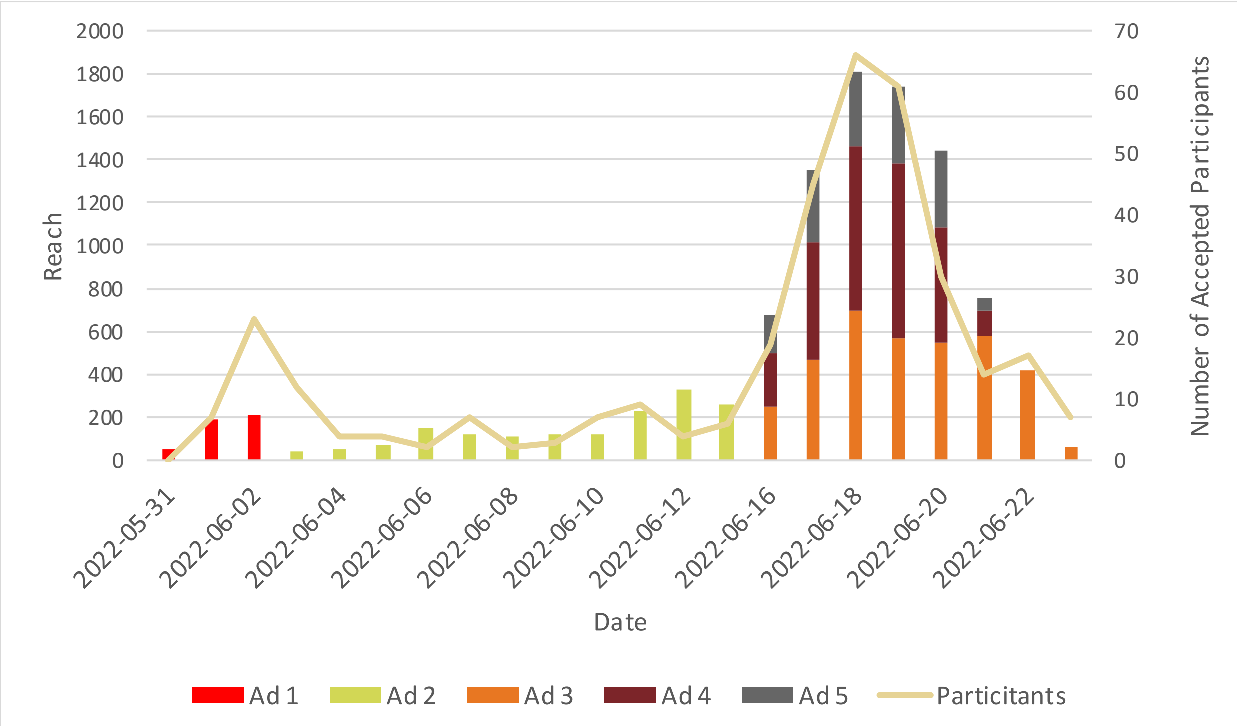

Figure 4-44 Reach vs. Number of Accepted Participants Per Day

Figure 4-45, Figure 4-46, and Figure 4-47 depict the timelines of daily result, link clicks, and ads cost from 05/31/22 to 06/23/22, respectively. Ads 1-2 applied strategy S1 that targets engagement while Ads 3-5 applied strategy S2 that targets link clicks. From Figure 4-45 and Figure 4-46, it can be seen that Ads 1 and 2 had engagements when they were active but almost had no link clicks (only one for the entire duration) while Ads 3-5 have certain link clicks most of the time. Combined with the timeline of ads daily cost shown in Figure 4-47, it appears that strategy S2 is more cost-effective than strategy S1 for recruiting survey participants. However, no conclusive result can be made regarding effective promotion strategy for HTS participant recruitment, due to limited data collected from the pilot study. Given the tremendous difference between the recruitment result with online ads promotion and without, and the big potential of online promotion, a further comprehensive investigation on online promotion strategies for HTS recruitment or related activity would be highly beneficial for future HTS studies and related TDOT research.

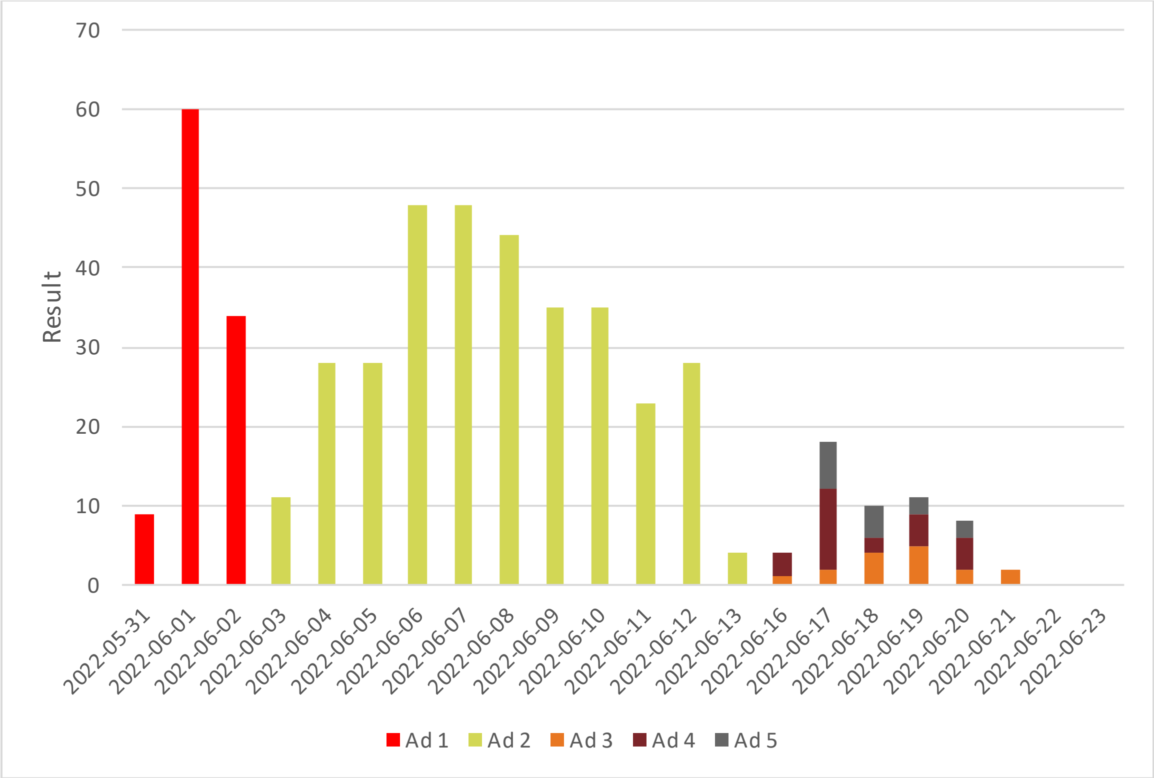

Figure 4-45 Timeline of Daily Result (Engagements for Ads 1-2 & Link Clicks for Ads 3-5)

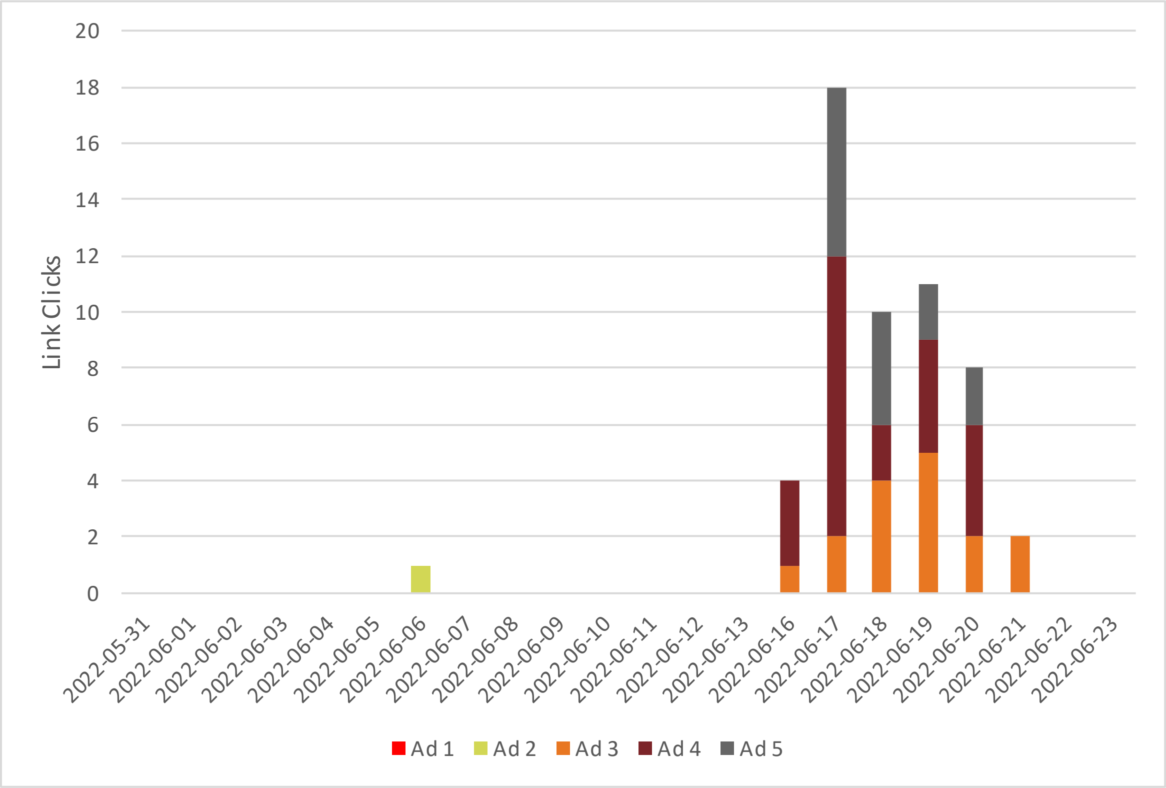

Figure 4-46 Timeline of Daily Link Clicks

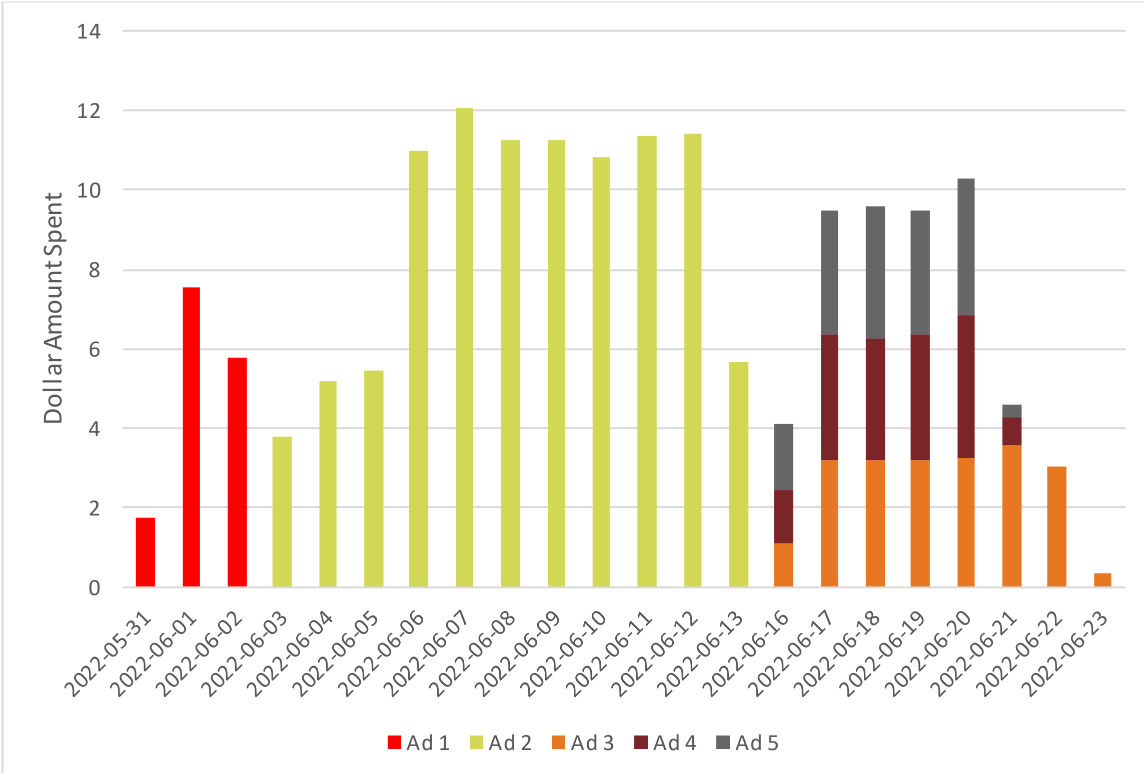

Figure 4-47 Timeline of Ads Daily Cost

Chapter 5 Conclusion

Thanks to the guidance and support from TDOT, we have completed this project successfully. Our initial objectives for the project have been met. First of all, we have developed and delivered a smartphone-based application, HTS@TN, for household travel surveys. All the communications between the HTS@TN mobile app and its server are securely transferred via standard network security protocols. The pilot survey study and app user feedback have demonstrated that the HTS@TN application is effective and scalable and can run for months. Second, the HTS@TN mobile app provides a convenient auto-tracking function through which users can submit travel information integrated with fine-grained GPS data. The auto-tracking function has been used by multiple survey participants in the pilot study and over 360 trips submitted contain GPS data. Third, we have validated the HTS@TN application by using it to run a pilot HTS for months. Over 200 survey participants from Tennessee or from a neighboring state of Tennessee completed the survey and submitted over 1,800 trips through the HTS@TN mobile app.

In the following of this chapter, we first summarize the benefits of this research to TDOT and then list a few recommendations for future research.

5.1 Benefits to TDOT

The research results and findings from this project bring the following benefits to TDOT:

1) **A tested, comprehensive smartphone app based HTS solution.** With the provided source code, database design, and detailed software deployment guide for the HTS@TN application, TDOT will be able to build all the application components including the server, web app, and mobile apps for Android and iOS, deploy them appropriately, and use the HTS@TN application to conduct a household travel survey of their choice. As HTS@TN is owned by TDOT, the software costs on performing HTS would be substantially reduced if HTS@TN is used. Although the first deployment of the application can take certain time and effort, that cost will be significantly reduced in subsequent deployments. Moreover, with all the source code, TDOT has freedom to customize the HTS@TN application, e.g., change some recruitment survey questions, add a new feature for trip logs, etc.
2) **Important findings about smartphone app based HTS gained from running the pilot survey study.** On one hand, the pilot survey study demonstrates that the HTS@TN application can reliably run for months with overall satisfying performance. On the other hand, the pilot survey study reveals the significance of social media in recruiting general survey participants as well as the importance of the mechanisms in place that can identify low-quality survey data and the participants who try to game the survey for rewards.
3) **An anonymized survey dataset for research exploration obtained from the pilot survey study.** The collected survey data was exported into files from the production database in the CSV format and anonymized for privacy purpose. Those CSV files can be easily imported into any mainstream database management systems or loaded into a program for data analysis. To preserve data integrity, no data records in the production database were manually deleted by the database administrator. Since this dataset contains fine-grained data records, i.e., GPS data points generated at second level, as well

as data records without GPS information and even low-quality data records with unreasonable trip information, it provides a unique opportunity for examining the variety of data records that can be submitted from participants and for developing appropriate methods to handle them. The fine-grained data records also allow for new methods to be developed to gain in-depth, multi-facet understanding of people's travel behavior.

5.2 Recommendations

Although the HTS@TN application has demonstrated its functionality, reliability, usability, and performance in practical use, there is room for new features to further enhance and extend the application. Based on our experience from application development and survey performance, the following functions/features are recommended as they would significantly enhance HTS@TN application and help TDOT improve the efficiency, quality, and research outcome of household travel surveys.

Automation of HTS Tasks and Fraud Detection/Prevention. In the pilot survey study, recruitment surveys and trips submitted were manually examined for participation approval and reward determination, respectively. Those manual examinations are time consuming. Certainly, automating such HTS tasks would substantially improve the work efficiency. However, the automation of those tasks needs to be carefully designed and applied, due to the challenge of fraud detection/prevention in HTS. Fake accounts and repeated, forged submissions by bots (programs for automatic submission) as well as human users are well-known problems to online software applications including mobile apps. For example, a large number of fake accounts and spam/scam messages exist on social media such as Facebook and Twitter and they are difficult to identify and remove. Submission of personally identifiable information usually is not required for HTS participants, which makes fraud detection more challenging for smartphone-based HTS. As we were concerned with this problem and there was not much information about it, we employed manual inspection in the pilot study. Over 400 users were declined to participate in the pilot survey and many of their recruitment surveys appear suspicious. It is also challenging for human examiners to tell genuine trip information from forged information without GPS data, which was optional in the pilot study. We developed ad-hoc rules to help manual inspection in the pilot study based on our experience with common issues and patterns of suspicious activities. Although they were useful, they were neither error proofing nor comprehensive. We believe automation of HTS tasks such as trip and recruitment validation should be pursued but it should be carefully designed with fraud detection/prevention built in from the beginning, extensively tested in real-world scenarios, and incrementally deployed with closely monitoring.

Survey Customization. Changes to household travel survey, e.g., changes of recruitment survey questions or trip log questions, are bound to happen. The HTS@TN application has already taken this into consideration in its design and implementation. For example, survey questions are not hardcoded in the application but are stored in a database, which makes changes to survey questions much easier. The settings of a survey, e.g., survey duration for each participant, ending date/time for the entire survey, are parameterized so that changes to settings of a survey can be easily made when a new survey is launched. In the future, more customization on survey administration and survey features may be needed for different HTS performed by TDOT. When needs for survey customization cannot be fully accommodated by the current version of HTS@TN, an incremental approach to expanding application support for survey customization is recommended. Customization needs should be carefully and thoroughly evaluated among all stakeholders of a survey before they are decided to be implemented in the application. Gradual incorporation of new features for survey customization is preferred to a radical change, which, however, should not be interpreted as always simply patching the application.

Software Updating. Very different from software development practices prior to the boom of smartphones and mobile apps, today's software systems, such as software frameworks, libraries, and mobile apps, are rapidly evolving and frequently upgraded to new versions, which often makes their older versions obsolete and incompatible. For example, Android platform and SDK have evolved many versions in the past ten years and certain packages, classes, and methods in old versions are not supported any more. Similar issues occur to many software frameworks and libraries. Consequently, applications that built upon older versions of software frameworks and libraries might not work well or not function at all with their new versions. Because of this, it is recommended to check code dependencies of the HTS@TN mobile apps (Android and iOS) and web app periodically with newer versions of platforms and libraries. Broken dependencies should be fixed promptly to keep the application up to date and readily deployable.

Data Visualization and Analytics. The HTS@TN web app provides a dashboard through which survey administrators can view the list of users, households, vehicles, trips, etc., filter a list using one of the criteria available in that list, view the detail of a household/vehicle/trip, and so on. However, no data analytics functionality is provided in the current version. Given their importance to research at TDOT, data analytic functions and features are recommended for future extension of the HTS@TN application. Data visualization and analytics with easy-to-use Web interfaces will help TDOT researchers easily access and interpret collected data through a Web browser and discover interesting patterns and insights from the data. Different visualization approaches, e.g., bar charts, pie charts, histogram, scatterplots, time series plots, boxplots, and multivariate data visualization, are recommended to be included to facilitate data exploration. A variety of common statistics analyses and machine learning methods should also be included. For example, statistics describing a group of participants or trips may include numeric measures of central tendency (mean, median, and mode) and measures of variability (range, deviation, variance, standard deviation, lower/inter/upper quartiles) of corresponding data sets. Machine learning classification methods may include decision trees, support vector machine, nearest neighbor classifiers, clustering methods, as well as deep learning schemes.

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Appendices

Appendix A HTS Enrollment Questionnaire

Household

1. What is your household address?

- [Enter street address]
- [Select city]
- [Select state]
- [Enter ZIP code]

2. (Optional) What type of housing do you live in?

i. Apartment
ii. Condo
iii. House
iv. Townhouse
v. Other

3. (Optional) What is your ownership status of your housing?

i. Own
ii. Rent
iii. Lease
iv. Other

4. (Optional) How many years have you lived in your current home? Please round up to the next full year (e.g. less than 1, enter 1; between 1 and 2, enter 2; etc.).

i. [Enter number]

5. (Optional) What is your total household income, before taxes, for last year. Include income from sources such as wages and salaries, income from a business or a farm, Social Security, pensions, dividends, interest, rent and any other income received for all household members.

i. Less than $10,000
ii. $10,000 to $14,999
iii. $15,000 to $24,999
iv. $25,000 to $34,999
v. $35,000 to $49,999
vi. $50,000 to $74,999
vii. $75,000 to $99,999
viii. $100,000 to $124,999
ix. $125,000 to $149,999
x. $150,000 to $199,999
xi. $200,000 or more

Household Members

Begin for each person, starting for the current user:

1. What's your/the person's legal name?
   i. [Enter name]

2. (Optional) What is this person's relationship to you? Relationships include biological, adopted and step.
   i. Self
   ii. Spouse/Unmarried partner
   iii. Child
   iv. Parent
   v. Brother/Sister
   vi. Other relative
   vii. Non-relative

3. (Optional) What's your/the person's age?
   i. [Enter age]

4. (Optional) What's your/the person's gender?
   i. Female
   ii. Male
   iii. Other

5. (Optional) Are you/Is this person of Hispanic or Latino origin?
   i. Yes, Hispanic or Latino
   ii. No, not Hispanic or Latino

6. (Optional) Which of the following describes your/this person's race?
   i. White
   ii. Black or African American
   iii. Asian
   iv. American Indian or Alaska native
   v. Native Hawaiian or other Pacific islander
   vi. Other

7. (Optional) What is your/this person's immigration status?
   i. US citizen
   ii. Permanent resident
   iii. Non-immigrant
   iv. Other

8. (Optional) What is your/this person's marital status?

i. Single, never married
ii. Married or domestic partnership
iii. Separated
iv. Widowed or divorced
v. Other

9. (Optional) What is your/the person's highest level of education?
   i. Less than a high school graduate
   ii. High school graduate or GED
   iii. Some college or associates degree
   iv. Bachelor's degree
   v. Graduate degree or professional degree

10. (Optional) What level of education are you/is this person currently attending?
    i. K-12th Grade including GED
    ii. Vocation/Technical/Trade School
    iii. Part-Time college/University
    iv. Full-Time college/University
    v. Other

11. (Optional) What is your/the person's employment status?
    i. Employed - Full Time
    ii. Employed - Part Time
    iii. Unemployed
    iv. Retired

12. (Optional) Which is your/this person's primary occupation?
    i. Managers
    ii. Professional
    iii. Technicians and associate professionals
    iv. Clerical support workers
    v. Service and sales workers
    vi. Skilled agricultural, forestry and fishery workers
    vii. Craft and related trades workers
    viii. Plant and machine operators, and assemblers
    ix. Elementary occupations
    x. Armed forces occupations

13. (Optional) How many jobs do you/does this person currently work?
    ii. [Enter number]

14. (Optional) Do you/Does this person work for either pay or profit?
    i. Yes
    ii. No

15. (Optional) Do you/Does this person work from home?
    i. Yes
    ii. No

16. (Optional) Are you/Is this person a seasonal worker?
    i. Yes
    ii. No

End for each person

Household Vehicle

Begin for each vehicle:

1. What is the year of this vehicle?
    i. [Enter number]

2. What is the make of this vehicle?
    i. [Select make]

3. What is the model of this vehicle?
    i. [Select model]

4. (Optional) What type of vehicle is it?
    i. Automobile/Car/Station Wagon
    ii. Van (Mini/Cargo/Passenger)
    iii. SUV (Santa Fe, Tahoe, Jeep, etc.)
    iv. Pickup Truck
    v. Other Truck
    vi. RV (Recreational Vehicle)
    vii. Motorcycle/Motorbike
    viii. Other

5. (Optional) What is the color of this vehicle?
    i. White
    ii. Silver
    iii. Black

iv. Grey
v. Blue
vi. Red
vii. Brown
viii. Green
ix. Other

6. (Optional) What type of fuel does this vehicle run on?
   i. Gas
   ii. Diesel
   iii. Hybrid
   iv. Electric
   v. Alternative fuel
   vi. Some other fuel

7. (Optional) Was the vehicle bought new or used?
   i. New
   ii. Used

8. (Optional) Does someone from your household drive this vehicle?
   i. Yes
   ii. No

9. (Optional) Who is the main driver of this vehicle?
   i. [Select household persons]

10. (Optional) How many years has your household had this vehicle?
    i. [Enter number]

11. (Optional) How many miles does this vehicle have on it?
    i. [Enter number]

12. (Optional) How many miles is this vehicle driven annually?
    i. [Enter number]

End for each vehicle

Appendix B HTS Trip Questions

Begin for each trip:

1. What is purpose of this trip?
    - i. Go home
    - ii. Work
    - iii. Work-related meeting / trip
    - iv. Volunteer activities (not paid)
    - v. Drop off /pick up someone
    - vi. Change type of transportation
    - vii. Attend school as a student
    - viii. Attend child care
    - ix. Attend adult care
    - x. Buy goods (groceries, clothes, appliances, gas)
    - xi. Buy services (dry cleaners, banking, service a car, pet care)
    - xii. Buy meals (go out for a meal, snack, carry-out)
    - xiii. Other general errands (post office, library)
    - xiv. Recreational activities (visit parks, movies, bars, museums)
    - xv. Exercise (go for a jog, walk, walk the dog, go to the gym)
    - xvi. Visit friends or relatives
    - xvii. Health care visit (medical, dental, therapy)
    - xviii. Religious or other community activities
    - xix. Other

2. What is the mode of transport?
    - i. Walk
    - ii. Bicycle
    - iii. Car
    - iv. SUV
    - v. Van
    - vi. Pickup truck
    - vii. Taxi / Limo (including Uber / Lyft)
    - viii. Rental car (including Zipcar / Car2Go)
    - ix. Golf cart / Segway
    - x. Motorcycle / Moped
    - xi. RV (motor home, ATV, snowmobile)
    - xii. School bus
    - xiii. Public or commuter bus
    - xiv. Paratransit / Dial-a-ride
    - xv. Private / Charter / Tour / Shuttle bus
    - xvi. City-to-city bus (Greyhound, Megabus)
    - xvii. Amtrak / Commuter rail
    - xviii. Subway / Elevated / Light rail / Street car
    - xix. Airplane
    - xx. Boat / Ferry / Water taxi

xxi. Other

3. What is the start address of this trip?
- [Enter street address]
- [Select city]
- [Select state]
- [Enter ZIP code]

4. What is the start time of this trip?
- [Enter time]

5. What is the destination address of this trip?
- [Enter street address]
- [Select city]
- [Select state]
- [Enter ZIP code]

6. What is the end time of this trip?
- [Enter time]

7. What is the estimated total distance in miles of this trip?
   i. [Enter distance]

8. What is the party size (How many people went with you, including you)?
   ii. [Enter number]

9. (Optional) Did you take your household vehicle for this trip?
   i. Yes
   ii. No

10. (Optional) Which vehicle did you take?
   i. [Select household vehicle]

End for each trip

Appendix C HTS@TN App Feedback Questions

1. How is your overall experience (on the scale of 5, the higher the better)?
    i. 1
    ii. 2
    iii. 3
    iv. 4
    v. 5

2. How is the functionality of our app (on the scale of 5, the higher the better)?
    i. 1
    ii. 2
    iii. 3
    iv. 4
    v. 5

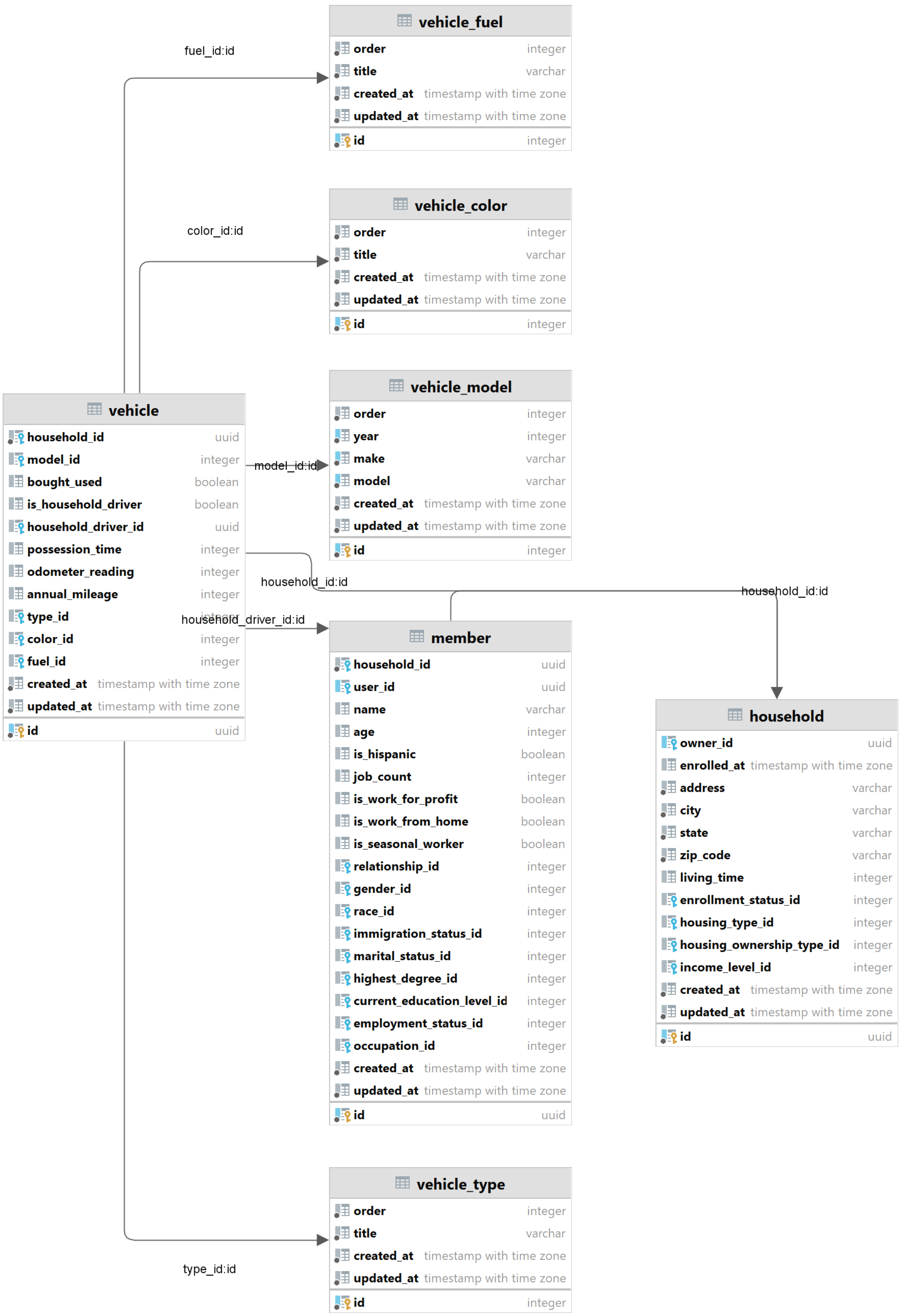
3. How is the usability of our app (on the scale of 5, the higher the better)?
    i. 1
    ii. 2
    iii. 3
    iv. 4
    v. 5

4. How is the stability of our app (on the scale of 5, the higher the better)?
    i. 1
    ii. 2
    iii. 3
    iv. 4
    v. 5

5. How is the look and feel of our app (on the scale of 5, the higher the better)?
    i. 1
    ii. 2
    iii. 3
    iv. 4
    v. 5

6. (Optional) How can we improve our app?
    i. [Enter details]

Appendix D Database UML Diagrams and Tables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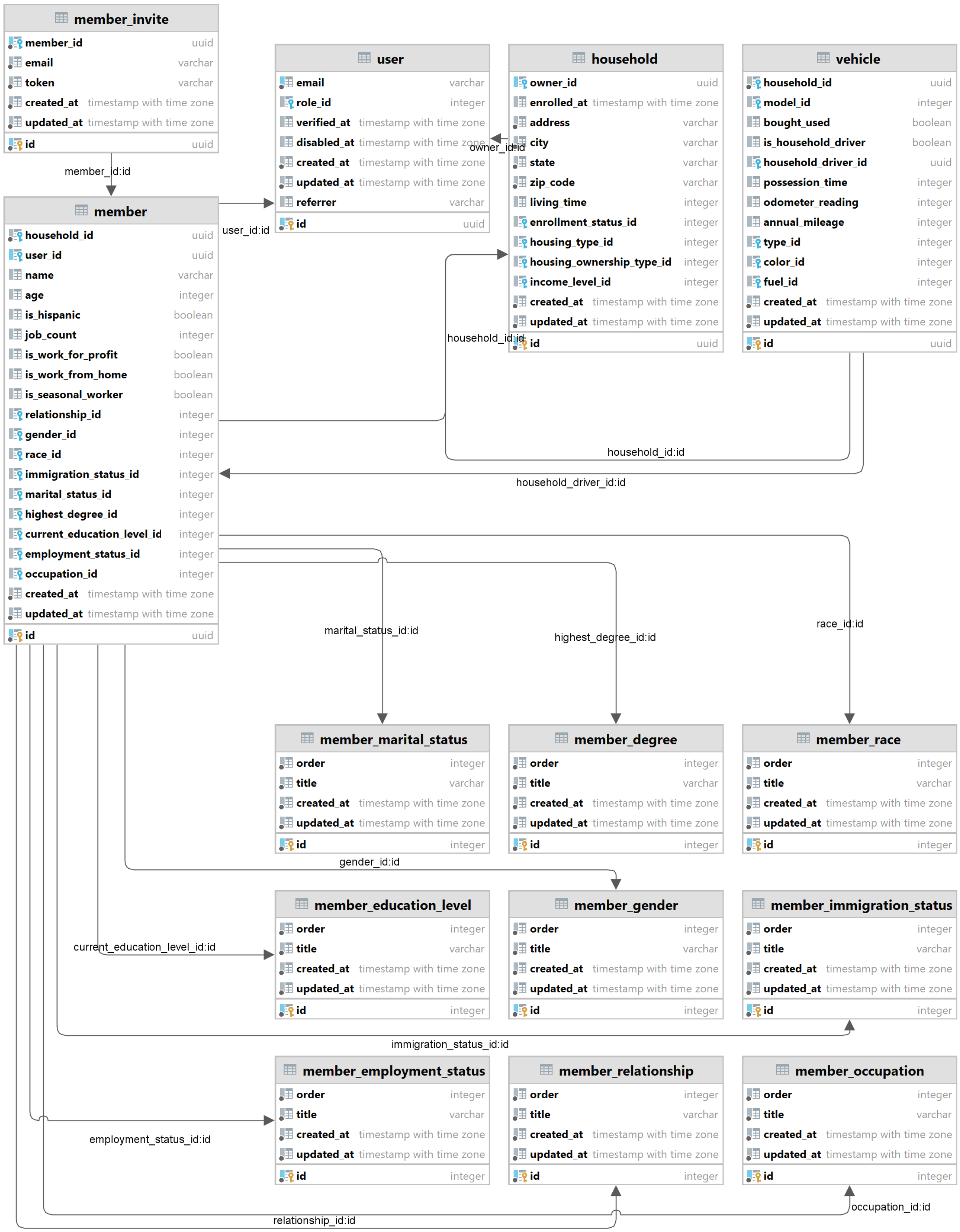
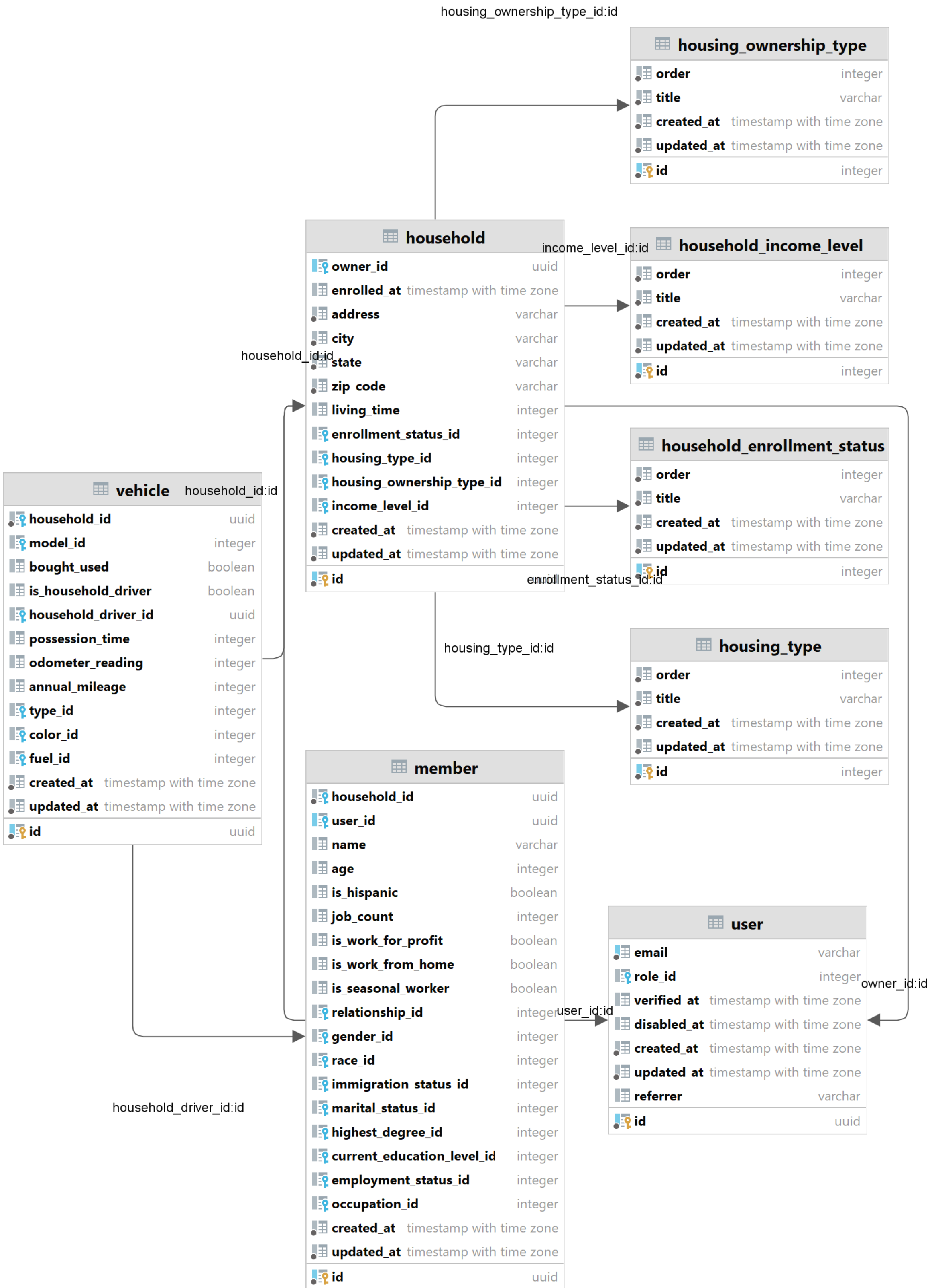
title varchar
created_at timestamp with time zone
updated_at timestamp with time zone
id integer
fuel_id:id
vehicle_color
order integer
title varchar
created_at timestamp with time zone
updated_at timestamp with time zone
id integer
color_id:id
vehicle_model
order integer
year integer
make varchar
model varchar
created_at timestamp with time zone
updated_at timestamp with time zone
id integer
model_id:id
vehicle
household_id uuid
model_id integer
bought_used boolean
is_household_driver boolean
household_driver_id uuid
possession_time integer
odometer_reading integer
annual_mileage integer
type_id integer
color_id integer
fuel_id integer
created_at timestamp with time zone
updated_at timestamp with time zone
id uuid
household_id:id
household_driver_id:id
household_id:id
member
household_id uuid
user_id uuid
name varchar
age integer
is_hispanic boolean
job_count integer
is_work_for_profit boolean
is_work_from_home boolean
is_seasonal_worker boolean
relationship_id integer
gender_id integer
race_id integer
immigration_status_id integer
marital_status_id integer
highest_degree_id integer
current_education_level_id integer
employment_status_id integer
occupation_id integer
created_at timestamp with time zone
updated_at timestamp with time zone
id uuid
household
owner_id uuid
enrolled_at timestamp with time zone
address varchar
city varchar
state varchar
zip_code varchar
living_time integer
enrollment_status_id integer
housing_type_id integer
housing_ownership_type_id integer
income_level_id integer
created_at timestamp with time zone
updated_at timestamp with time zone
id uuid
vehicle_type
order integer
title varchar
created_at timestamp with time zone
updated_at timestamp with time zone
id integer
type_id:id



member_invite
member_id uuid
email varchar
token varchar
created_at timestamp with time zone
updated_at timestamp with time zone
id uuid
member_id:id
member
household_id uuid
user_id uuid
name varchar
age integer
is_hispanic boolean
job_count integer
is_work_for_profit boolean
is_work_from_home boolean
is_seasonal_worker boolean
relationship_id integer
gender_id integer
race_id integer
immigration_status_id integer
marital_status_id integer
highest_degree_id integer
current_education_level_id integer
employment_status_id integer
occupation_id integer
created_at timestamp with time zone
updated_at timestamp with time zone
id uuid
user
email varchar
role_id integer
verified_at timestamp with time zone
disabled_at timestamp with time zone
created_at timestamp with time zone
updated_at timestamp with time zone
referrer varchar
id uuid
user_id:id
owner_id:id
household
owner_id uuid
enrolled_at timestamp with time zone
address varchar
city varchar
state varchar
zip_code varchar
living_time integer
enrollment_status_id integer
housing_type_id integer
housing_ownership_type_id integer
income_level_id integer
created_at timestamp with time zone
updated_at timestamp with time zone
id uuid
household_id:id
vehicle
household_id uuid
model_id integer
bought_used boolean
is_household_driver boolean
household_driver_id uuid
possession_time integer
odometer_reading integer
annual_mileage integer
type_id integer
color_id integer
fuel_id integer
created_at timestamp with time zone
updated_at timestamp with time zone
id uuid
household_id:id
household_driver_id:id
marital_status_id:id
highest_degree_id:id
race_id:id
member_marital_status
order integer
title varchar
created_at timestamp with time zone
updated_at timestamp with time zone
id integer
member_degree
order integer
title varchar
created_at timestamp with time zone
updated_at timestamp with time zone
id integer
member_race
order integer
title varchar
created_at timestamp with time zone
updated_at timestamp with time zone
id integer
gender_id:id
member_education_level
order integer
title varchar
created_at timestamp with time zone
updated_at timestamp with time zone
id integer
member_gender
order integer
title varchar
created_at timestamp with time zone
updated_at timestamp with time zone
id integer
member_immigration_status
order integer
title varchar
created_at timestamp with time zone
updated_at timestamp with time zone
id integer
current_education_level_id:id
immigration_status_id:id
member_employment_status
order integer
title varchar
created_at timestamp with time zone
updated_at timestamp with time zone
id integer
member_relationship
order integer
title varchar
created_at timestamp with time zone
updated_at timestamp with time zone
id integer
member_occupation
order integer
title varchar
created_at timestamp with time zone
updated_at timestamp with time zone
id integer
employment_status_id:id
relationship_id:id
occupation_id:id


housing_ownership_type_id:id
housing_ownership_type
order integer
title varchar
created_at timestamp with time zone
updated_at timestamp with time zone
id integer
household
owner_id uuid
enrolled_at timestamp with time zone
address varchar
city varchar
state varchar
zip_code varchar
living_time integer
enrollment_status_id integer
housing_type_id integer
housing_ownership_type_id integer
income_level_id integer
created_at timestamp with time zone
updated_at timestamp with time zone
id uuid
income_level_id:id
household_income_level
order integer
title varchar
created_at timestamp with time zone
updated_at timestamp with time zone
id integer
household_id:id
household_enrollment_status
order integer
title varchar
created_at timestamp with time zone
updated_at timestamp with time zone
id integer
enrollment_status_id:id
vehicle
household_id:id
household_id uuid
model_id integer
bought_used boolean
is_household_driver boolean
household_driver_id uuid
possession_time integer
odometer_reading integer
annual_mileage integer
type_id integer
color_id integer
fuel_id integer
created_at timestamp with time zone
updated_at timestamp with time zone
id uuid
housing_type_id:id
housing_type
order integer
title varchar
created_at timestamp with time zone
updated_at timestamp with time zone
id integer
member
household_id uuid
user_id uuid
name varchar
age integer
is_hispanic boolean
job_count integer
is_work_for_profit boolean
is_work_from_home boolean
is_seasonal_worker boolean
relationship_id integer
gender_id integer
race_id integer
immigration_status_id integer
marital_status_id integer
highest_degree_id integer
current_education_level_id integer
employment_status_id integer
occupation_id integer
created_at timestamp with time zone
updated_at timestamp with time zone
id uuid
user
email varchar
role_id integer
verified_at timestamp with time zone
disabled_at timestamp with time zone
created_at timestamp with time zone
updated_at timestamp with time zone
referrer varchar
id uuid
owner_id:id
user_id:id
household_driver_id:id

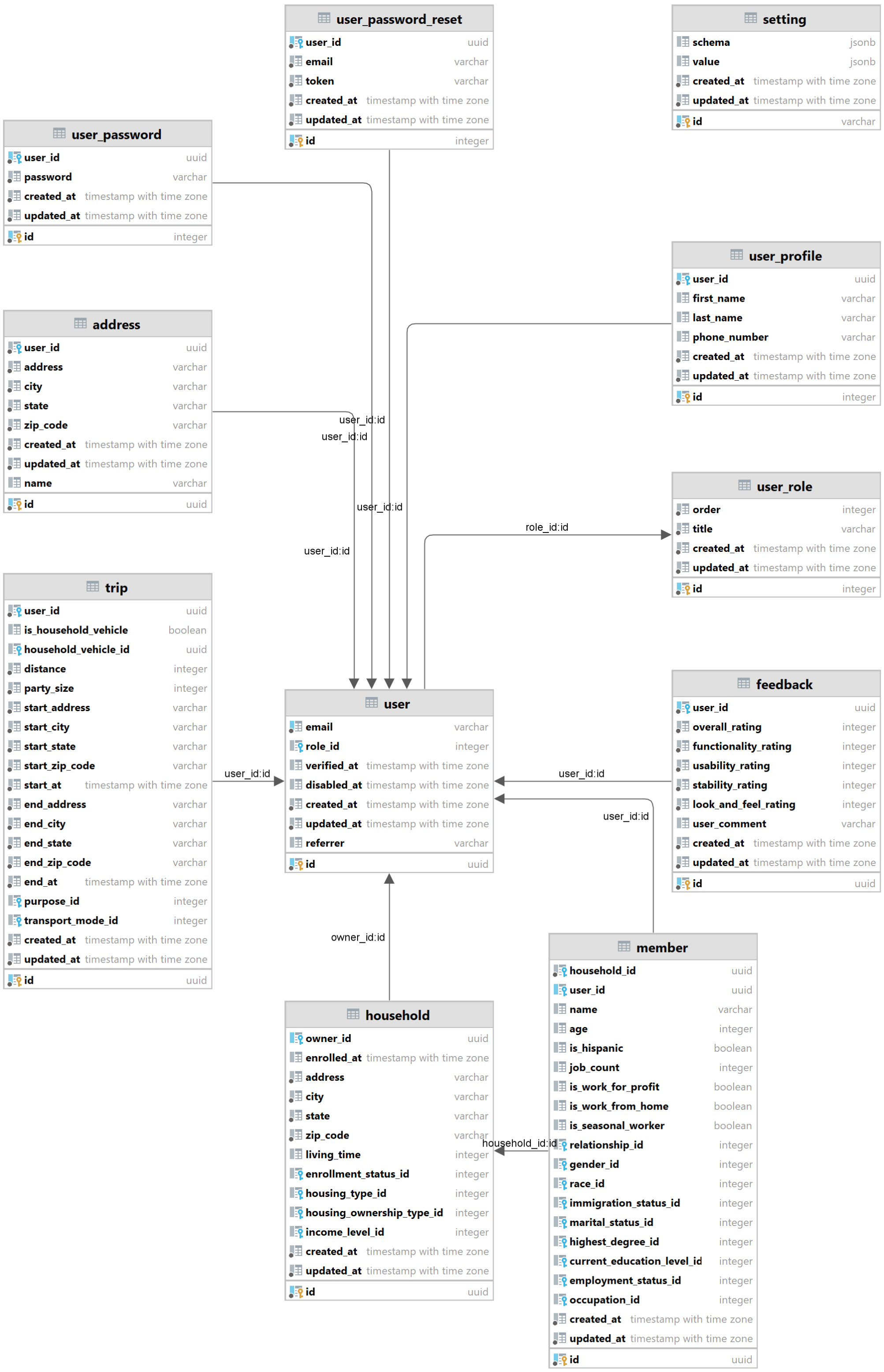

user_password_reset
user_id uuid
email varchar
token varchar
created_at timestamp with time zone
updated_at timestamp with time zone
id integer
setting
schema jsonb
value jsonb
created_at timestamp with time zone
updated_at timestamp with time zone
id varchar
user_password
user_id uuid
password varchar
created_at timestamp with time zone
updated_at timestamp with time zone
id integer
user_profile
user_id uuid
first_name varchar
last_name varchar
phone_number varchar
created_at timestamp with time zone
updated_at timestamp with time zone
id integer
address
user_id uuid
address varchar
city varchar
state varchar
zip_code varchar
created_at timestamp with time zone
updated_at timestamp with time zone
name varchar
id uuid
user_id:id
user_id:id
user_id:id
user_id:id
role_id:id
user_role
order integer
title varchar
created_at timestamp with time zone
updated_at timestamp with time zone
id integer
trip
user_id uuid
is_household_vehicle boolean
household_vehicle_id uuid
distance integer
party_size integer
start_address varchar
start_city varchar
start_state varchar
start_zip_code varchar
start_at timestamp with time zone
end_address varchar
end_city varchar
end_state varchar
end_zip_code varchar
end_at timestamp with time zone
purpose_id integer
transport_mode_id integer
created_at timestamp with time zone
updated_at timestamp with time zone
id uuid
user
email varchar
role_id integer
verified_at timestamp with time zone
disabled_at timestamp with time zone
created_at timestamp with time zone
updated_at timestamp with time zone
referrer varchar
id uuid
user_id:id
user_id:id
user_id:id
feedback
user_id uuid
overall_rating integer
functionality_rating integer
usability_rating integer
stability_rating integer
look_and_feel_rating integer
user_comment varchar
created_at timestamp with time zone
updated_at timestamp with time zone
id uuid
owner_id:id
member
household_id uuid
user_id uuid
name varchar
age integer
is_hispanic boolean
job_count integer
is_work_for_profit boolean
is_work_from_home boolean
is_seasonal_worker boolean
relationship_id integer
gender_id integer
race_id integer
immigration_status_id integer
marital_status_id integer
highest_degree_id integer
current_education_level_id integer
employment_status_id integer
occupation_id integer
created_at timestamp with time zone
updated_at timestamp with time zone
id uuid
household
owner_id uuid
enrolled_at timestamp with time zone
address varchar
city varchar
state varchar
zip_code varchar
living_time integer
enrollment_status_id integer
housing_type_id integer
housing_ownership_type_id integer
income_level_id integer
created_at timestamp with time zone
updated_at timestamp with time zone
id uuid
household_id:id

Table	member_race	
Description	A lookup table for member's race type	
Column	**Data Type**	**Comment**
id	uuid	Member race type ID
order	integer	The display order of this record
title	varchar	The title of race type
created_at	timestamp	Creation time of the record
updated_at	timestamp	Last update time of the record

Table	member_relationship	
Description	A lookup table for member's relationship to household owner	
Column	**Data Type**	**Comment**
id	uuid	Member relationship ID
order	integer	The display order of this record
title	varchar	The title of relationship type
created_at	timestamp	Creation time of the record
updated_at	timestamp	Last update time of the record

Table	setting	
Description	This table stores global site settings	
Column	**Data Type**	**Comment**
id	uuid	Setting ID
schema	json	Validation schema of the setting
value	json	Setting value
created_at	timestamp	Creation time of the record
updated_at	timestamp	Last update time of the record

Table	trip	
Description	This table stores all trips submitted by users	
Column	**Data Type**	**Comment**
id	uuid	Trip ID
user_id	uuid	ID of the submitting user
is_household_vehicle	boolean	Whether the trip is taken using a household vehicle
household_vehicle_id	uuid	ID of the household vehicle used for this trip
distance	integer	Total trip distance in miles
party_size	integer	Size of the group that the user traveled with
start_address	varchar	The street address of the trip origin location
start_city	varchar	The city name of the trip origin location
start_state	varchar	The state abbreviation of the trip origin location
start_zip_code	varchar	The postal code of the trip origin location
start_at	timestamp	The date and time when origin started

end_address	varchar	The street address of the trip destination location
end_city	varchar	The city name of the trip destination location
end_state	varchar	The state abbreviation of the trip destination location
end_zip_code	varchar	The postal code of the trip destination location
end_at	timestamp	The date and time when destination started
purpose_id	integer	ID of the trip purpose type
transport_mode_id	integer	ID of the trip transport mode type
created_at	timestamp	Creation time of the record
updated_at	timestamp	Last update time of the record

Table	trip_coordinate	
Description	This table stores the GPS coordinates of all trips	
Column	**Data Type**	**Comment**
id	uuid	GPS coordinate ID
trip_id	uuid	ID of the trip that this coordinate belongs to
time	timestamp	Date and time the coordinate is recorded
lat	double	Latitude
lng	double	Longitude
alt	double	Altitude
dir	double	Bearing in degrees
spd	double	Speed in meters per second
hac	double	Horizontal accuracy radius in meters
vac	double	Altitude accuracy in meters
dac	double	Bearing accuracy in degrees
sac	double	Speed accuracy in meters per second
created_at	timestamp	Creation time of the record
updated_at	timestamp	Last update time of the record

Table	trip_purpose	
Description	A lookup table for trip purpose types	
Column	**Data Type**	**Comment**
id	uuid	Trip purpose ID
order	integer	The display order of this record
title	varchar	The title of trip purpose
created_at	timestamp	Creation time of the record
updated_at	timestamp	Last update time of the record

Table	trip_transport_mode	
Description	A lookup table for trip transport mode types	
Column	**Data Type**	**Comment**
id	uuid	Trip transport mode ID

order	integer	The display order of this record
title	varchar	The title of trip transport mode
created_at	timestamp	Creation time of the record
updated_at	timestamp	Last update time of the record

Table	user	
Description	This table stores account information of all users	
Column	**Data Type**	**Comment**
id	uuid	User ID
email	varchar	The user account email
role_id	integer	ID of the user role
verified_at	timestamp	Date and time user account email is verified, if any
disabled_at	timestamp	Date and time user account is disabled, if any
created_at	timestamp	Creation time of the record
updated_at	timestamp	Last update time of the record
referrer	varchar	The referrer code entered by the user during registration, if any

Table	user_password	
Description	This table stores password information of all users	
Column	**Data Type**	**Comment**
id	uuid	User password ID
user_id	uuid	User ID
password	varchar	Hash of the password
created_at	timestamp	Creation time of the record
updated_at	timestamp	Last update time of the record

Table	user_password_reset	
Description	This table stores password reset request submitted by the user	
Column	**Data Type**	**Comment**
id	uuid	User password reset request ID
user_id	uuid	User ID
email	varchar	User account email
token	varchar	User password reset token
created_at	timestamp	Creation time of the record
updated_at	timestamp	Last update time of the record

Table	user_profile	
Description	This table stores user profile information	
Column	**Data Type**	**Comment**
id	uuid	User profile ID
user_id	uuid	User ID

first_name	varchar	User's first name
last_name	varchar	User's last name
phone_number	varchar	User's phone number
created_at	timestamp	Creation time of the record
updated_at	timestamp	Last update time of the record

Table	user_role	
Description	A lookup table for user role types	
Column	**Data Type**	**Comment**
id	uuid	User role ID
order	integer	The display order of this record
title	varchar	The title of user role
created_at	timestamp	Creation time of the record
updated_at	timestamp	Last update time of the record

Table	vehicle	
Description	This table stores all user-submitted vehicle information	
Column	**Data Type**	**Comment**
id	uuid	Vehicle ID
household_id	uuid	ID of the household this vehicle belongs to
model_id	integer	ID of the vehicle model
bought_used	boolean	Whether the vehicle is used when bought by the household
is_household_driver	boolean	Whether the vehicle is regularly driven by household member
household_driver_id	uuid	ID of the household member who drive this vehicle regularly
possession_time	integer	Number of years the household possesses this vehicle
odometer_reading	integer	The odometer reading of this vehicle in miles
annual_mileage	integer	Number of miles the vehicle is driven per year
type_id	integer	ID of the vehicle type
color_id	integer	ID of the vehicle paint color
fuel_id	integer	ID of the vehicle fuel type
created_at	timestamp	Creation time of the record
updated_at	timestamp	Last update time of the record

Table	vehicle_color	
Description	A lookup table for vehicle paint colors	
Column	**Data Type**	**Comment**
id	uuid	Vehicle paint color ID
order	integer	The display order of this record
title	varchar	The title of vehicle paint color

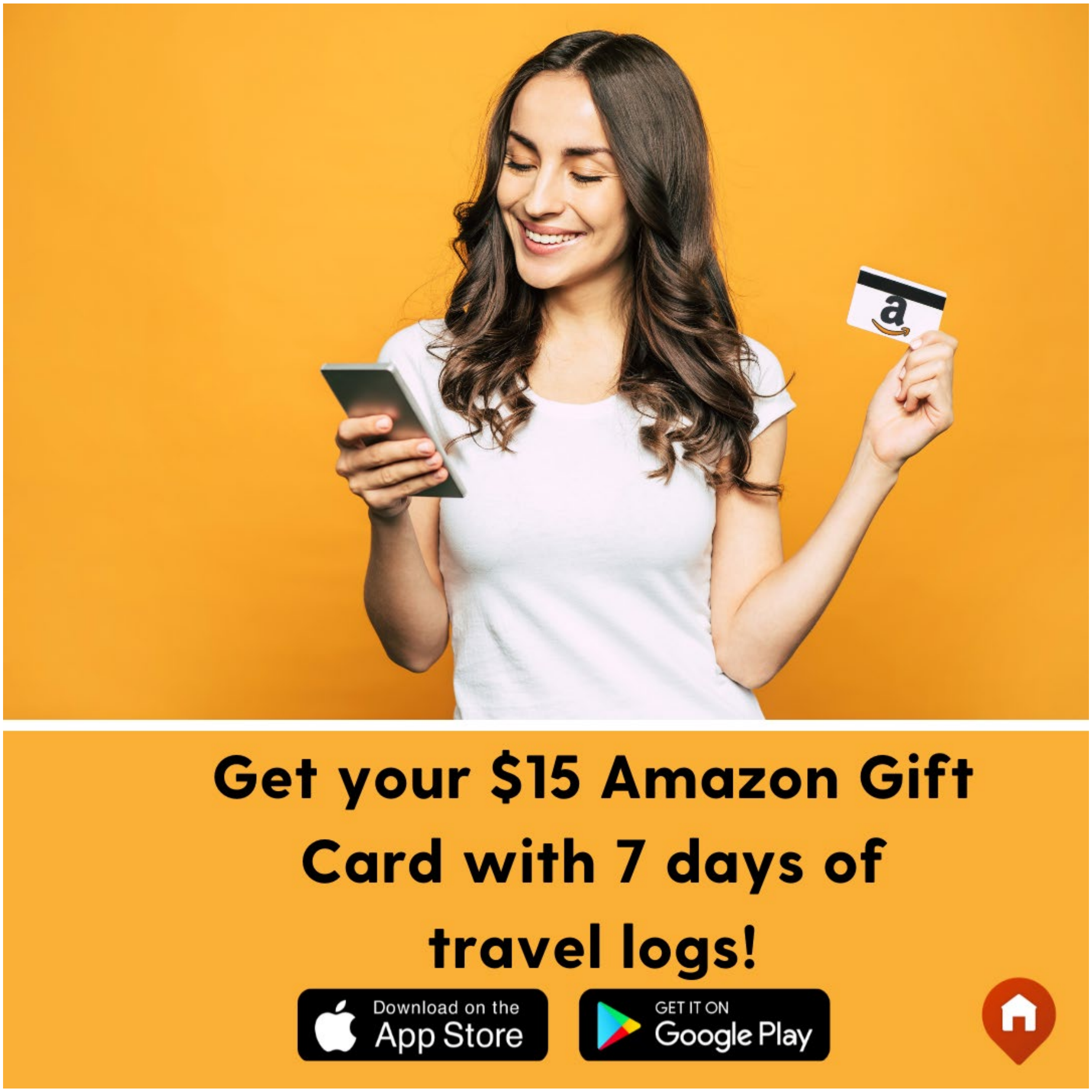
created_at	timestamp	Creation time of the record
updated_at	timestamp	Last update time of the record

Table	vehicle_fuel	
Description	A lookup table for vehicle fuel types	
Column	**Data Type**	**Comment**
id	uuid	Vehicle fuel type ID
order	integer	The display order of this record
title	varchar	The title of vehicle fuel type
created_at	timestamp	Creation time of the record
updated_at	timestamp	Last update time of the record

Table	vehicle_model	
Description	A lookup table for vehicle year, make, and model combinations	
Column	**Data Type**	**Comment**
id	uuid	Vehicle year, make, model combination ID
order	integer	The display order of this record
year	integer	The vehicle year
make	varchar	The vehicle brand name
model	varchar	The vehicle model name
created_at	timestamp	Creation time of the record
updated_at	timestamp	Last update time of the record

Table	vehicle_type	
Description	A lookup table for vehicle types	
Column	**Data Type**	**Comment**
id	uuid	Vehicle type ID
order	integer	The display order of this record
title	varchar	The title of vehicle type
created_at	timestamp	Creation time of the record
updated_at	timestamp	Last update time of the record

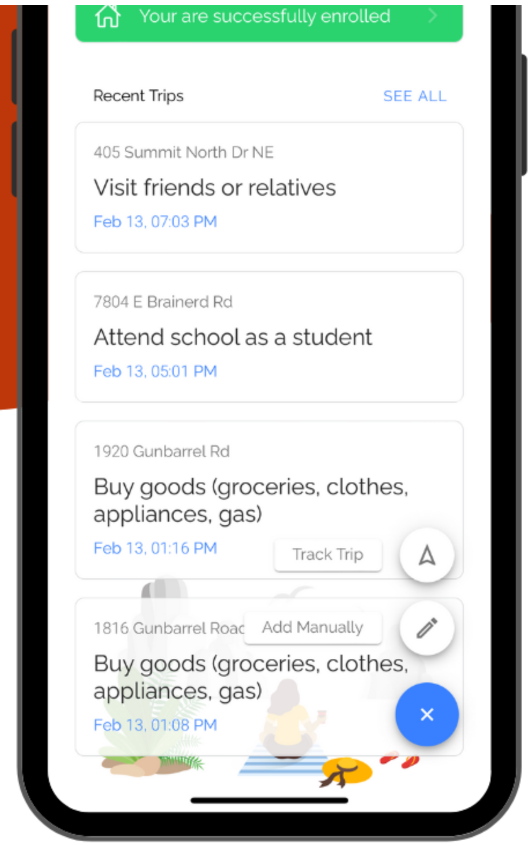
Appendix E Sample Images for Survey Promotion on Social Media


Get your $15 Amazon Gift Card with 7 days of travel logs!
Download on the App Store
GET IT ON Google Play


Get your $15 Amazon Gift Card with 7 days of travel logs!
Download on the App Store
GET IT ON Google Play

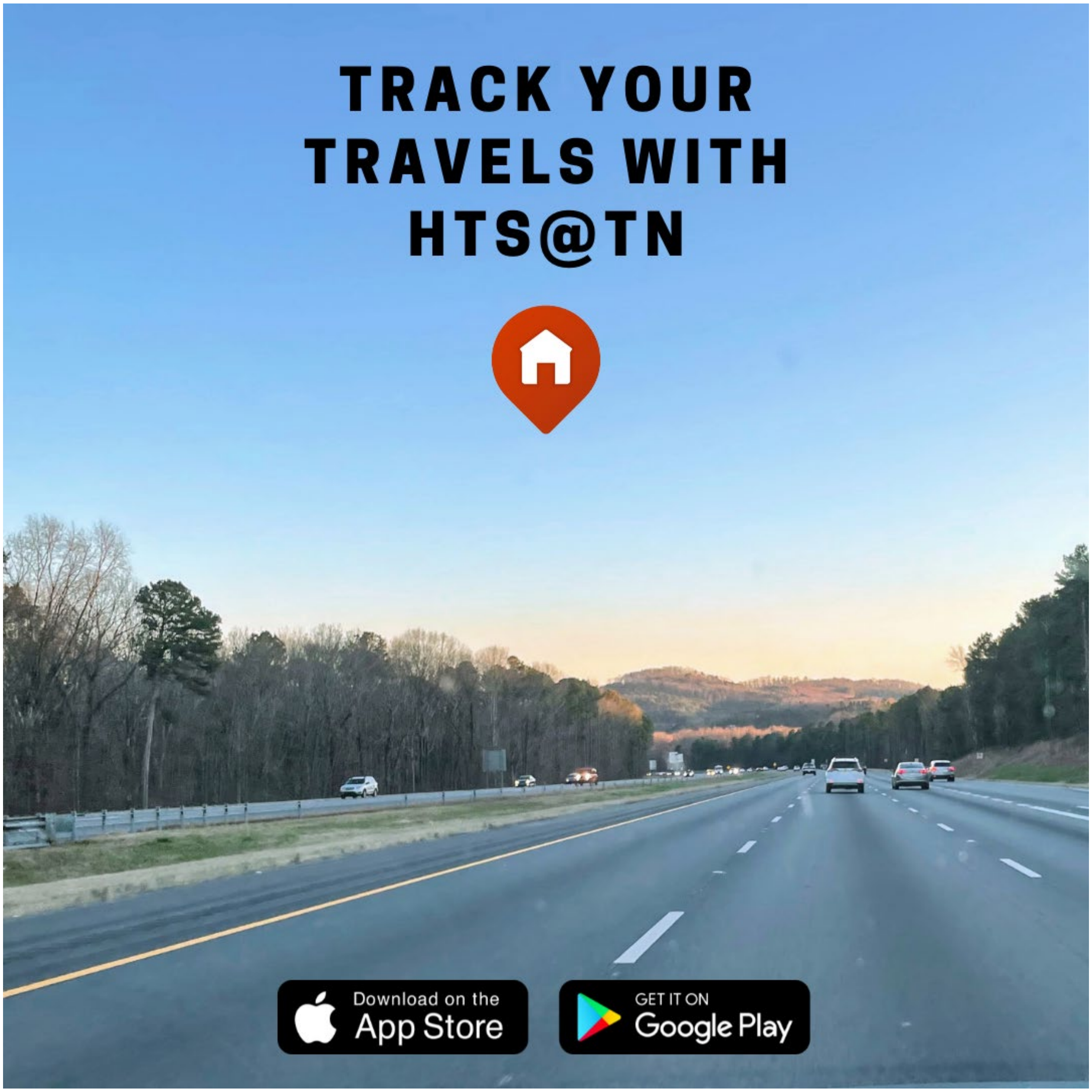
@htsattn

DOWNLOAD OUR APP TO GET CASHBACK!



Download on the App Store

GET IT ON Google Play


TRACK YOUR TRAVELS WITH HTS@TN
Download on the App Store
GET IT ON Google Play

Appendix F HTS@TN App Terms of Service

These Terms of Service govern your use of HTS@TN, our website located at https://tdotproject.research.utc.edu, and any related services provided by the NEXUS Lab.

When you create an HTS@TN account or use HTS@TN, you agree to abide by these Terms of Service and to comply with all applicable laws and regulations. If you do not agree with these Terms of Service, you are prohibited from further using the app, accessing our website, or using any other services provided by NEXUS Lab.

If you access or download HTS@TN from (1) the Apple App Store, you agree to any Usage Rules set forth in the App Store Terms of Service; and/or (2) the Google Play Store, you agree to the Android, Google Inc. Terms and Conditions including the Google Apps Terms of Service.

We, NEXUS Lab, reserve the right to review and amend any of these Terms of Service at our sole discretion. Upon doing so, we will update this page and notify you through the app and/or the email address you provided when you created your account. Any changes to these Terms of Service will take effect immediately from the date of publication.

These Terms of Service were last updated on 11 May 2021.

1. Limitations of Use

By using HTS@TN and our website, you warrant on behalf of yourself, any entity who you represent who has entered into these Terms of Service, and your users that you will not:

1. modify, copy, prepare derivative works of, decompile, or reverse engineer HTS@TN or any materials and software contained within HTS@TN or on our website;
2. remove any copyright or other proprietary notations from HTS@TN or any materials and software contained within HTS@TN or on our website;
3. transfer HTS@TN or any of its associated materials to another person or “mirror” the materials on any other server;
4. knowingly or negligently use HTS@TN or any of its associated services in a way that abuses or disrupts our networks or any other service NEXUS Lab provides;
5. use HTS@TN or its associated services to transmit or publish any harassing, indecent, obscene, fraudulent, or unlawful material;
6. use HTS@TN or its associated services in violation of any applicable laws or regulations;
7. use HTS@TN to send unauthorized advertising or spam;
8. harvest, collect, or gather user data without the user’s consent; or
9. use HTS@TN or its associated services in such a way that may infringe the privacy, intellectual property rights, or other rights of third parties.

2. Intellectual Property

The intellectual property in the materials in HTS@TN and on our website are owned by or licensed to NEXUS Lab. You may download HTS@TN, to view, use, and display the application on your mobile device for your personal use only.

This constitutes the grant of a license, not a transfer of title. This license shall automatically terminate if you violate any of these restrictions or these Terms of Service, and may be terminated by NEXUS Lab at any time.

3. User-Generated Content

You retain your intellectual property ownership rights over content you submit to us for publication within HTS@TN and/or on its corresponding website. We will never claim ownership of your content, but we do require a license from you in order to use it.

When you use HTS@TN or its associated services to post, upload, share, or otherwise transmit content covered by intellectual property rights, you grant to us a non-exclusive, royalty-free, transferable, sub-licensable, worldwide license to use, distribute, modify, run, copy, publicly display, translate, or otherwise create derivative works of your content in a manner that is consistent with your privacy preferences and our Privacy Policy.

The license you grant us can be terminated at any time by deleting your content or account. However, to the extent that we (or our partners) have used your content in connection with commercial or sponsored content, the license will continue until the relevant commercial or post has been discontinued by us.

You give us permission to use your username and other identifying information associated with your account in a manner that is consistent with your privacy preferences, and our Privacy Policy.

4. Automatic Updates

You give us permission to download and install updates to HTS@TN on your device in accordance with your privacy preferences. This permission can be revoked at any time by deleting HTS@TN from your device.

5. Liability

HTS@TN and the materials in HTS@TN and on our website are provided on an 'as is' basis. To the extent permitted by law, NEXUS Lab makes no warranties, expressed or implied, and hereby disclaims and negates all other warranties including, without limitation, implied warranties or conditions of merchantability, fitness for a particular purpose, or non-infringement of intellectual property, or other violation of rights.

In no event shall NEXUS Lab or its suppliers be liable for any consequential loss suffered or incurred by you or any third party arising from the use or inability to use HTS@TN, our website, or any other services provided by NEXUS Lab or the materials in HTS@TN, even if NEXUS Lab or an authorized representative has been notified, orally or in writing, of the possibility of such damage.

In the context of this agreement, “consequential loss” includes any consequential loss, indirect loss, real or anticipated loss of profit, loss of benefit, loss of revenue, loss of business, loss of goodwill, loss of opportunity, loss of savings, loss of reputation, loss of use and/or loss or corruption of data, whether under statute, contract, equity, tort (including negligence), indemnity, or otherwise.

Because some jurisdictions do not allow limitations on implied warranties, or limitations of liability for consequential or incidental damages, these limitations may not apply to you.

6. Accuracy of Materials

The materials appearing in HTS@TN or on our website are not comprehensive and are for general information purposes only. To the extent permitted by law, NEXUS Lab does not warrant or make any representations concerning the accuracy, likely results, or reliability of the use of the materials in HTS@TN or on our website, or otherwise relating to such materials or on any resources linked to HTS@TN and our website.

7. Links

NEXUS Lab has not reviewed all of the sites linked to HTS@TN or on its corresponding website and is not responsible for the contents of any such linked site. The inclusion of any link does not imply endorsement, approval, or control by NEXUS Lab of the site. Use of any such linked website is at your own risk and we strongly advise you make your own investigations with respect to the suitability of those sites.

8. Notice regarding Apple

To the extent that you are using or accessing HTS@TN on an iOS device, you acknowledge and agree to the terms of this clause. You acknowledge that these Terms of Service are between you and NEXUS Lab only, not with Apple Inc. (Apple), and Apple is not responsible for HTS@TN and any materials available in HTS@TN.

Apple has no obligation to furnish you with any maintenance and support services with respect to HTS@TN.

If HTS@TN fails to conform to any applicable warranty, you may notify Apple and Apple will refund the purchase price of the mobile application to you. To the maximum extent permitted by applicable law, Apple will have no other warranty obligation whatsoever with respect to HTS@TN and any other claims, losses, liabilities, damages, costs, or expenses attributable to any failure to conform to any warranty will be our responsibility.

Apple is not responsible for addressing any claims by you or any third party relating to HTS@TN or your use of HTS@TN, including but not limited to (1) product liability claims; (2) any claim that our mobile application fails to conform to any applicable legal or regulatory requirement; and (3) claims arising under consumer protection or similar legislation.

Apple is not responsible for the investigation, defence, settlement, and discharge of any third-party claim that our mobile application infringes that third party's intellectual property rights.

You agree to comply with any applicable third-party terms when using HTS@TN, including any Usage Rules set forth in the Apple App Store Agreement of Service.

Apple and Apple's subsidiaries are third-party beneficiaries of these Terms of Service, and upon your acceptance of these Terms of Service, Apple will have the right (and will be deemed to have accepted the right) to enforce these Terms of Service against you as a third-party beneficiary of these Terms of Service.

You hereby represent and warrant that (1) you are not located in a country that is subject to a U.S. Government embargo, or that has been designated by the U.S. Government as a "terrorist supporting" country; and (2) you are not listed on any U.S. Government list of prohibited or restricted parties.

9. Right to Terminate

We may suspend or terminate your HTS@TN account and right to use HTS@TN and these Terms of Service immediately upon written notice to you for any breach of these Terms of Service.

10. Severance

Any term of these Terms of Service which is wholly or partially void or unenforceable is severed to the extent that it is void or unenforceable. The validity of the remainder of these Terms of Service is not affected.

11. Governing Law

These Terms of Service are governed by and construed in accordance with the laws of Tennessee, USA. You irrevocably submit to the exclusive jurisdiction of the courts in that State or location.

Appendix G HTS@TN App Privacy Policy

Your privacy is important to us. It is NEXUS Lab's policy to respect your privacy and comply with any applicable law and regulation regarding any personal information we may collect about you, including via our app, HTS@TN, and its associated services.

Personal information is any information about you which can be used to identify you. This includes information about you as a person (such as name, address, and date of birth), your devices, payment details, and even information about how you use an app or online service.

In the event our app contains links to third-party sites and services, please be aware that those sites and services have their own privacy policies. After following a link to any third-party content, you should read their posted privacy policy information about how they collect and use personal information. This Privacy Policy does not apply to any of your activities after you leave our app.

This policy is effective as of 18 June 2021.

Last updated: 18 June 2021

1. Information We Collect

Information we collect falls into one of two categories: “voluntarily provided” information and “automatically collected” information.

“Voluntarily provided” information refers to any information you knowingly and actively provide us when using our app and its associated services.

“Automatically collected” information refers to any information automatically sent by your device in the course of accessing our app and its associated services.

1.1 Log Data

When you access our servers via our app, we may automatically log the standard data provided by your device. It may include your device's Internet Protocol (IP) address, your device type and version, your activity within the app, time and date, and other details about your usage.

Additionally, when you encounter certain errors while using the app, we automatically collect data about the error and the circumstances surrounding its occurrence. This data may include technical details about your device, what you were trying to do when the error happened, and other technical information relating to the problem. You may or may not receive notice of such errors, even in the moment they occur, that they have occurred, or what the nature of the error is.

Please be aware that while this information may not be personally identifying by itself, it may be possible to combine it with other data to personally identify individual persons.

1.2 Device Data

Our app may access and collect data via your device's in-built tools, such as:

- Location data
- Hardware information (e.g., device brand, model)
- System information (e.g., OS version, network status)

When you install the app or use your device's tools within the app, we request permission to access this information. The specific data we collect can depend on the individual settings of your device and the permissions you grant when you install and use the app.

1.3 Personal Information

We may ask for personal information — for example, when you submit content to us or when you contact us — which may include one or more of the following:

- Name
- Email
- Phone/mobile number
- Home/mailing address
- Employment and education data
- Household information

1.3.1 Sensitive Information

"Sensitive information" or "special categories of data" is a subset of personal information that is given a higher level of protection. Examples of sensitive information include information relating to your racial or ethnic origin, political opinions, religion, trade union or other professional associations or memberships, philosophical beliefs, sexual orientation, sexual practices or sex life, criminal records, health information, or biometric information.

The types of sensitive information that we may collect about you include:

- Racial or ethnic origin
- Demographics (e.g., age, gender, race, etc.)
- Marital status

We will not collect sensitive information about you without first obtaining your consent, and we will only use or disclose your sensitive information as permitted, required, or authorized by law.

1.4 User-Generated Content

We consider "user-generated content" to be materials (text, image and/or video content) voluntarily supplied to us by our users for the purpose of publication on our platform, website or re-publishing on our social media channels. All user-generated content is associated with the account or email address used to submit the materials.

Please be aware that any content you submit for the purpose of publication will be public after posting (and subsequent review or vetting process). Once published, it may be accessible to third parties not covered under this privacy policy.

1.5 Legitimate Reasons for Processing Your Personal Information

We only collect and use your personal information when we have a legitimate reason for doing so. In which instance, we only collect personal information that is reasonably necessary to provide our services to you.

1.6 Collection and Use of Information

We may collect personal information from you when you do any of the following on our website:

- Register for an account
- Enter any of our competitions, contests, sweepstakes, and surveys

- Use a mobile device or web browser to access our content
- Contact us via email, social media, or on any similar technologies
- When you mention us on social media

We may collect, hold, use, and disclose information for the following purposes, and personal information will not be further processed in a manner that is incompatible with these purposes:

- to provide you with our app and platform's core features and services
- to contact and communicate with you
- to consider your enrollment application
- to enable you to access and use our app, associated platforms, and associated social media channels
- for internal record keeping and administrative purposes
- to run competitions, sweepstakes, and/or offer additional benefits to you

We may combine voluntarily provided and automatically collected personal information with general information or research data we receive from other trusted sources. For example, If you consent to us accessing your social media profiles, we may combine information sourced from those profiles with information received from you directly to provide you with an enhanced experience of our app and services.

1.7 Security of Your Personal Information

When we collect and process personal information, and while we retain this information, we will protect it within commercially acceptable means to prevent loss and theft, as well as unauthorized access, disclosure, copying, use, or modification.

Although we will do our best to protect the personal information you provide to us, we advise that no method of electronic transmission or storage is 100% secure, and no one can guarantee absolute data security.

You are responsible for selecting any password and its overall security strength, ensuring the security of your own information within the bounds of our services. For example, ensuring any passwords associated with accessing your personal information and accounts are secure and confidential.

1.8 How Long We Keep Your Personal Information

We keep your personal information only for as long as we need to. This time period may depend on what we are using your information for, in accordance with this privacy policy. For example, if you have provided us with personal information as part of creating an account with us, we may retain this information for the duration your account exists on our system. If your personal information is no longer required for this purpose, we will delete it or make it anonymous by removing all details that identify you.

However, if necessary, we may retain your personal information for our compliance with a legal, accounting, or reporting obligation or for archiving purposes in the public interest, scientific, or historical research purposes or statistical purposes.

2. Children's Privacy

We do not aim any of our products or services directly at children under the age of 13, and we do not knowingly collect personal information about children under 13.

3. Disclosure of Personal Information to Third Parties

We may disclose personal information to:

- a parent, subsidiary, or affiliate of our company
- third-party service providers for the purpose of enabling them to provide their services, including (without limitation) IT service providers, data storage, hosting and server providers, error loggers, debt collectors, maintenance or problem-solving providers, professional advisors, and payment systems operators
- our employees, contractors, and/or related entities
- our existing or potential agents or business partners
- sponsors or promoters of any competition, sweepstakes, or promotion we run
- credit reporting agencies, courts, tribunals, and regulatory authorities, in the event you fail to pay for goods or services we have provided to you
- courts, tribunals, regulatory authorities, and law enforcement officers, as required by law, in connection with any actual or prospective legal proceedings, or in order to establish, exercise, or defend our legal rights
- third parties, including agents or sub-contractors, who assist us in providing information, products, services, or direct marketing to you
- third parties to collect and process data
- an entity that buys, or to which we transfer all or substantially all of our assets and business

Third parties we currently use include:

- Map and geolocation service
- Error logging service

4. International Transfers of Personal Information

The personal information we collect is stored and/or processed in United States, or where we or our partners, affiliates, and third-party providers maintain facilities.

The countries to which we store, process, or transfer your personal information may not have the same data protection laws as the country in which you initially provided the information. If we transfer your personal information to third parties in other countries: (i) we will perform those transfers in accordance with the requirements of applicable law; and (ii) we will protect the transferred personal information in accordance with this privacy policy.

5. Your Rights and Controlling Your Personal Information

Your choice: By providing personal information to us, you understand we will collect, hold, use, and disclose your personal information in accordance with this privacy policy. You do not have to provide personal information to us, however, if you do not, it may affect your use of our app or the products and/or services offered on or through it.

Information from third parties: If we receive personal information about you from a third party, we will protect it as set out in this privacy policy. If you are a third party providing personal information about somebody else, you represent and warrant that you have such person's consent to provide the personal information to us.

Marketing permission: If you have previously agreed to us using your personal information for direct marketing purposes, you may change your mind at any time by contacting us using the details below.

Access: You may request details of the personal information that we hold about you.

Correction: If you believe that any information we hold about you is inaccurate, out of date, incomplete, irrelevant, or misleading, please contact us using the details provided in this privacy policy. We will take reasonable steps to correct any information found to be inaccurate, incomplete, misleading, or out of date.

Non-discrimination: We will not discriminate against you for exercising any of your rights over your personal information. Unless your personal information is required to provide you with a particular service or offer (for example serving particular content to your device), we will not deny you goods or services and/or charge you different prices or rates for goods or services, including through granting discounts or other benefits, or imposing penalties, or provide you with a different level or quality of goods or services.

Notification of data breaches: We will comply with laws applicable to us in respect of any data breach.

Complaints: If you believe that we have breached a relevant data protection law and wish to make a complaint, please contact us using the details below and provide us with full details of the alleged breach. We will promptly investigate your complaint and respond to you, in writing, setting out the outcome of our investigation and the steps we will take to deal with your complaint. You also have the right to contact a regulatory body or data protection authority in relation to your complaint.

Unsubscribe: To unsubscribe from our email database or opt-out of communications (including marketing communications), please contact us using the details provided in this privacy policy, or opt-out using the opt-out facilities provided in the communication. We may need to request specific information from you to help us confirm your identity.

6. Business Transfers

If we or our assets are acquired, or in the unlikely event that we go out of business or enter bankruptcy, we would include data, including your personal information, among the assets transferred to any parties who acquire us. You acknowledge that such transfers may occur, and that any parties who acquire us may, to the extent permitted by applicable law, continue to use your personal information according to this policy, which they will be required to assume as it is the basis for any ownership or use rights we have over such information.

7. Limits of Our Policy

Our app may link to external sites that are not operated by us. Please be aware that we have no control over the content and policies of those sites, and cannot accept responsibility or liability for their respective privacy practices.

8. Changes to This Policy

At our discretion, we may change our privacy policy to reflect updates to our business processes, current acceptable practices, or legislative or regulatory changes. If we decide to change this privacy policy, we will post the changes here and on our website.

If the changes are significant, or if required by applicable law, we will contact you (based on your selected preferences for communications from us) and all our registered users with the new details and links to the updated or changed policy.

If required by law, we will get your permission or give you the opportunity to opt in to or opt out of, as applicable, any new uses of your personal information.

9. Additional Disclosures for General Data Protection Regulation (GDPR) Compliance (EU)

9.1 Data Controller / Data Processor

The GDPR distinguishes between organizations that process personal information for their own purposes (known as "data controllers") and organizations that process personal information on behalf of other organizations (known as "data processors"). We, NEXUS Lab, located at the address provided in our Contact Us section, are a Data Controller with respect to the personal information you provide to us.

9.2 Legal Bases for Processing Your Personal Information

We will only collect and use your personal information when we have a legal right to do so. In which case, we will collect and use your personal information lawfully, fairly, and in a transparent manner. If we seek your consent to process your personal information, and you are under 16 years of age, we will seek your parent or legal guardian's consent to process your personal information for that specific purpose.

Our lawful bases depend on the services you use and how you use them. This means we only collect and use your information on the following grounds:

9.2.1 Consent from You

Where you give us consent to collect and use your personal information for a specific purpose. You may withdraw your consent at any time using the facilities we provide; however this will not affect any use of your information that has already taken place. You may consent to providing your name and contact details for the purpose of entering a giveaway or promotion. While you may withdraw your entry at any time, this will not affect any selection or judging that has already taken place. If you have any further enquiries about how to withdraw your consent, please feel free to enquire using the details provided in the Contact Us section of this privacy policy.

9.2.2 Performance of a Contract or Transaction

Where you have entered into a contract or transaction with us, or in order to take preparatory steps prior to our entering into a contract or transaction with you. For example, we need technical information about your device in order to provide the essential features of our app.

9.2.3 Our Legitimate Interests

Where we assess it is necessary for our legitimate interests, such as for us to provide, operate, improve and communicate our services. For example, we collect technical information about your device in order to improve and personalize your experience of our app. We consider our legitimate interests to include research and development, understanding our audience, marketing and promoting our services, measures taken to operate our services efficiently, marketing analysis, and measures taken to protect our legal rights and interests.

9.2.4 Compliance with Law

In some cases, we may have a legal obligation to use or keep your personal information. Such cases may include (but are not limited to) court orders, criminal investigations, government requests, and regulatory obligations. If you have any further enquiries about how we retain personal information in order to comply with the law, please feel free to enquire using the details provided in the Contact Us section of this privacy policy.

9.3 International Transfers Outside of the European Economic Area (EEA)

We will ensure that any transfer of personal information from countries in the European Economic Area (EEA) to countries outside the EEA will be protected by appropriate safeguards, for example by using standard data protection clauses approved by the European Commission, or the use of binding corporate rules or other legally accepted means.

9.4 Your Rights and Controlling Your Personal Information

Restrict: You have the right to request that we restrict the processing of your personal information if (i) you are concerned about the accuracy of your personal information; (ii) you believe your personal information has been unlawfully processed; (iii) you need us to maintain the personal information solely for the purpose of a legal claim; or (iv) we are in the process of considering your objection in relation to processing on the basis of legitimate interests.

Objecting to processing: You have the right to object to processing of your personal information that is based on our legitimate interests or public interest. If this is done, we must provide compelling legitimate grounds for the processing which overrides your interests, rights, and freedoms, in order to proceed with the processing of your personal information.

Data portability: You may have the right to request a copy of the personal information we hold about you. Where possible, we will provide this information in CSV format or other easily readable machine format. You may also have the right to request that we transfer this personal information to a third party.

Deletion: You may have a right to request that we delete the personal information we hold about you at any time, and we will take reasonable steps to delete your personal information from our current records. If you ask us to delete your personal information, we will let you know how the deletion affects your use of our app, website or products and services. There may be exceptions to this right for specific legal reasons which, if applicable, we will set out for you in response to your request. Please be aware that search engines and similar third parties may still retain copies of your personal information that has been made public at least once, like certain profile information and public comments, even after you have deleted the information from our services or deactivated your account.

10. Additional Disclosures for California Compliance (US)

Under California Civil Code Section 1798.83, if you live in California and your business relationship with us is mainly for personal, family, or household purposes, you may ask us about the information we release to other organizations for their marketing purposes.

To make such a request, please contact us using the details provided in this privacy policy with "Request for California privacy information" in the subject line. You may make this type of request once every calendar year. We will email you a list of categories of personal information we revealed to other organizations for their marketing purposes in the last calendar year, along with their names and addresses. Not all personal information shared in this way is covered by Section 1798.83 of the California Civil Code.

10.1 Do Not Track

Some browsers have a "Do Not Track" feature that lets you tell websites that you do not want to have your online activities tracked. At this time, we do not respond to browser "Do Not Track" signals.

We adhere to the standards outlined in this privacy policy, ensuring we collect and process personal information lawfully, fairly, transparently, and with legitimate, legal reasons for doing so.

10.2 Cookies and Pixels

At all times, you may decline cookies from our site if your browser permits. Most browsers allow you to activate settings on your browser to refuse the setting of all or some cookies. Accordingly, your ability to limit cookies is based only on your browser's capabilities. Please refer to the Cookies section of this privacy policy for more information.

10.3 CCPA-Permitted Financial Incentives

In accordance with your right to non-discrimination, we may offer you certain financial incentives permitted by the CCPA that can result in different prices, rates, or quality levels for the goods or services we provide.

Any CCPA-permitted financial incentive we offer will reasonably relate to the value of your personal information, and we will provide written terms that describe clearly the nature of such an offer. Participation in a financial incentive program requires your prior opt-in consent, which you may revoke at any time.

10.4 California Notice of Collection

We will collect the following categories of personal information enumerated in the California Consumer Privacy Act:

- Demographics, such as your age or gender. This category includes data that may qualify as protected classifications under other California or federal laws.
- Geolocation data.
- Employment and education data, such as data you provide when you apply for a job with us.

For more information on information we collect, including the sources we receive information from, review the "Information We Collect" section. We collect and use these categories of personal information for the business purposes described in the "Collection and Use of Information" section, including to provide and manage our Service.

10.5 Right to Know and Delete

If you are a California resident, you have rights to delete your personal information we collected and know certain information about our data practices in the preceding 12 months. In particular, you have the right to request the following from us:

- The categories of personal information we have collected about you;
- The categories of sources from which the personal information was collected;
- The categories of personal information about you we disclosed for a business purpose or sold;
- The categories of third parties to whom the personal information was disclosed for a business purpose or sold;
- The business or commercial purpose for collecting or selling the personal information; and
- The specific pieces of personal information we have collected about you.

To exercise any of these rights, please contact us using the details provided in this privacy policy.

10.6 Shine the Light

If you are a California resident, in addition to the rights discussed above, you have the right to request information from us regarding the manner in which we share certain personal information as defined by California's "Shine the Light" with third parties and affiliates for their own direct marketing purposes.

To receive this information, send us a request using the contact details provided in this privacy policy. Requests must include "California Privacy Rights Request" in the first line of the description and include your name, street address, city, state, and ZIP code.

11. Contact Us

For any questions or concerns regarding your privacy, you may contact us using the following details:

NEXUS Lab

ut_htshelp@live.utk.edu

Appendix G HTS@TN App Acceptable Use Policy

This acceptable use policy covers the products, services, and technologies (collectively referred to as the "Products") provided by NEXUS Lab under any ongoing agreement. It's designed to protect us, our customers, and the general Internet community from unethical, irresponsible, and illegal activity.

NEXUS Lab customers found engaging in activities prohibited by this acceptable use policy can be liable for service suspension and account termination. In extreme cases, we may be legally obliged to report such customers to the relevant authorities.

This policy was last reviewed on 11 May 2021.

1. Fair Use

We provide our facilities with the assumption your use will be "business as usual", as per our offer schedule. If your use is considered to be excessive, then additional fees may be charged, or capacity may be restricted.

We are opposed to all forms of abuse, discrimination, rights infringement, and/or any action that harms or disadvantages any group, individual, or resource. We expect our customers and, where applicable, their users ("end-users") to likewise engage our Products with similar intent.

2. Customer Accountability

We regard our customers as being responsible for their own actions as well as for the actions of anyone using our Products with the customer's permission. This responsibility also applies to anyone using our Products on an unauthorized basis as a result of the customer's failure to put in place reasonable security measures.

By accepting Products from us, our customers agree to ensure adherence to this policy on behalf of anyone using the Products as their end users. Complaints regarding the actions of customers or their end-users will be forwarded to the nominated contact for the account in question.

If a customer — or their end-user or anyone using our Products as a result of the customer — violates our acceptable use policy, we reserve the right to terminate any Products associated with the offending account or the account itself or take any remedial or preventative action we deem appropriate, without notice. To the extent permitted by law, no credit will be available for interruptions of service resulting from any violation of our acceptable use policy.

3. Prohibited Activity

3.1 Copyright infringement and access to unauthorized material

Our Products must not be used to transmit, distribute or store any material in violation of any applicable law. This includes but isn't limited to:

- any material protected by copyright, trademark, trade secret, or other intellectual property right used without proper authorization, and
- any material that is obscene, defamatory, constitutes an illegal threat or violates export control laws.

The customer is solely responsible for all material they input, upload, disseminate, transmit, create or publish through or on our Products, and for obtaining legal permission to use any works included in such material.

3.2 SPAM and unauthorized message activity

Our Products must not be used for the purpose of sending unsolicited bulk or commercial messages in violation of the laws and regulations applicable to your jurisdiction (“spam”). This includes but isn’t limited to sending spam, soliciting customers from spam sent from other service providers, and collecting replies to spam sent from other service providers.

Our Products must not be used for the purpose of running unconfirmed mailing lists or telephone number lists (“messaging lists”). This includes but isn’t limited to subscribing email addresses or telephone numbers to any messaging list without the permission of the email address or telephone number owner, and storing any email addresses or telephone numbers subscribed in this way. All messaging lists run on or hosted by our Products must be “confirmed opt-in”. Verification of the address or telephone number owner’s express permission must be available for the lifespan of the messaging list.

We prohibit the use of email lists, telephone number lists or databases purchased from third parties intended for spam or unconfirmed messaging list purposes on our Products.

This spam and unauthorized message activity policy applies to messages sent using our Products, or to messages sent from any network by the customer or any person on the customer’s behalf, that directly or indirectly refer the recipient to a site hosted via our Products.

3.3 Unethical, exploitative, and malicious activity

Our Products must not be used for the purpose of advertising, transmitting, or otherwise making available any software, program, product, or service designed to violate this acceptable use policy, or the acceptable use policy of other service providers. This includes but isn’t limited to facilitating the means to send spam and the initiation of network sniffing, pinging, packet spoofing, flooding, mail-bombing, and denial-of-service attacks.

Our Products must not be used to access any account or electronic resource where the group or individual attempting to gain access does not own or is not authorized to access the resource (e.g. “hacking”, “cracking”, “phreaking”, etc.).

Our Products must not be used for the purpose of intentionally or recklessly introducing viruses or malicious code into our Products and systems.

Our Products must not be used for purposely engaging in activities designed to harass another group or individual. Our definition of harassment includes but is not limited to denial-of-service attacks, hate-speech, advocacy of racial or ethnic intolerance, and any activity intended to threaten, abuse, infringe upon the rights of, or discriminate against any group or individual.

Other activities considered unethical, exploitative, and malicious include:

1. Obtaining (or attempting to obtain) services from us with the intent to avoid payment;
2. Using our facilities to obtain (or attempt to obtain) services from another provider with the intent to avoid payment;
3. The unauthorized access, alteration, or destruction (or any attempt thereof) of any information about our customers or end-users, by any means or device;

4. Using our facilities to interfere with the use of our facilities and network by other customers or authorized individuals;
5. Publishing or transmitting any content of links that incite violence, depict a violent act, depict child pornography, or threaten anyone's health and safety;
6. Any act or omission in violation of consumer protection laws and regulations;
7. Any violation of a person's privacy.

Our Products may not be used by any person or entity, which is involved with or suspected of involvement in activities or causes relating to illegal gambling; terrorism; narcotics trafficking; arms trafficking or the proliferation, development, design, manufacture, production, stockpiling, or use of nuclear, chemical or biological weapons, weapons of mass destruction, or missiles; in each case including any affiliation with others whatsoever who support the above such activities or causes.

3.4 Unauthorized use of NEXUS Lab property

We prohibit the impersonation of NEXUS Lab, the representation of a significant business relationship with NEXUS Lab, or ownership of any NEXUS Lab property (including our Products and brand) for the purpose of fraudulently gaining service, custom, patronage, or user trust.

4. About This Policy

This policy outlines a non-exclusive list of activities and intent we deem unacceptable and incompatible with our brand.

We reserve the right to modify this policy at any time by publishing the revised version on our website. The revised version will be effective from the earlier of:

- the date the customer uses our Products after we publish the revised version on our website; or
- 30 days after we publish the revised version on our website.

Appendix H HTS@TN Mobile App User Manual

1. Introduction

1.1 Description

HTS@TN is an account-based household travel survey solution that is completed in its entirely through a mobile application available on both Google and the App Store. After account approval, the approved account will have an allotted 7 days to log their travels and complete their survey. HTS@TN's aim is to gather travel data in Tennessee to better understand when and where people are traveling. To do this, at the user's discretion, HTS@TN makes use of their phone's GPS information to log the route they travel.

1.2 Document Information

This document was created to outline the functionality of the HTS@TN travel survey. Contained in this document include a description of the HTS@TN app, instructions on how to set up an account, how to log trips, the qualifications for a reward, and information about settings and functions of the application

1.3 Items Necessary for Survey

To participate in the HTS@TN travel survey, you need to have

- Residence in Tennessee. The HTS@TN travel survey is exclusive to residents of Tennessee. Thus, in order to participate, users are required to provide a valid address in Tennessee before account approval.
- Access to a method of travel. As HTS@TN is a travel survey, users will need access to transportation to log trips. Some valid forms of travel include a personal car, a bike, or public transit to name a few.
- A mobile device with internet access. As HTS@TN is a mobile application, users will be required access to a mobile device with access to the Apple App Store or Google Play Store. Additionally, this device will require internet connection to upload trips.

2. Users

2.1 User Registration

To begin registration, first download and install the HTS@TN application from the Google Play or App Store.

After installation, open the HTS@TN app. Select 'Sign Up' underneath the Login button. You will be brought to the HTS@TN sign-up page where you will be prompted to enter your personal information to create your account.

2.2 Enrollment Survey

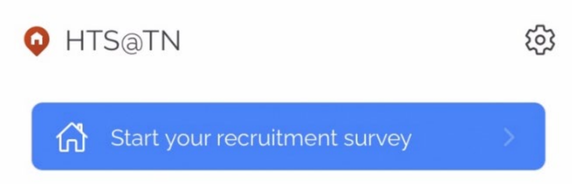


Figure 2.2.1 Recruitment survey popup

After creating your HTS@TN account, you must complete the recruitment survey to confirm your eligibility for the study. Start by pressing the large blue button at the top of the HTS@TN dashboard labeled 'Start your recruitment survey.'

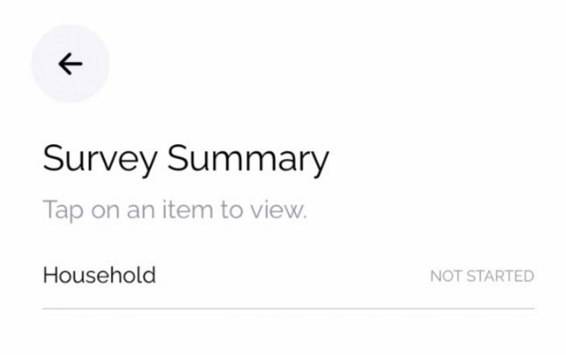


Figure 2.2.2 Initial survey summary screen

You will be taken to the Survey Summary screen. At first, you will only have access to the Household survey, which will be labeled 'Not Started.' Tap the label to begin this portion of the survey.

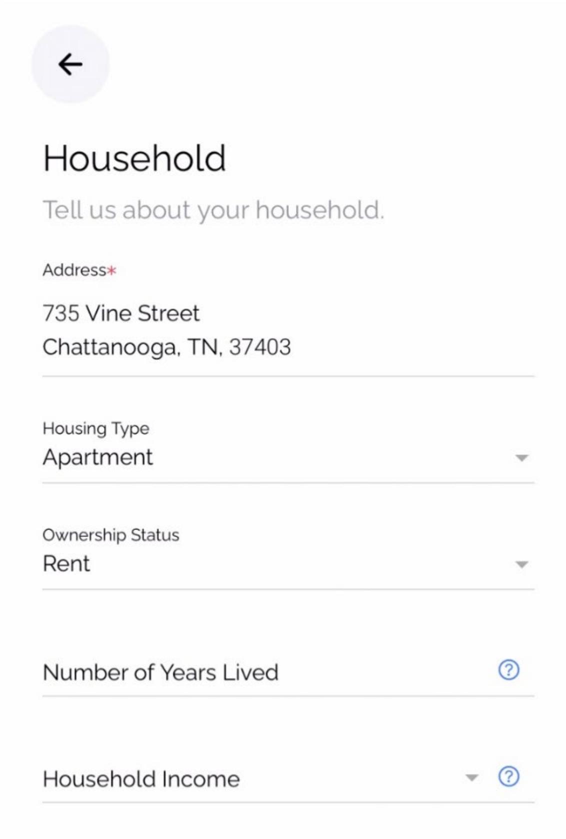


Figure 2.2.3 Household survey questions

You will be brought to the Household Survey screen and asked a series of questions pertaining to your household, such as the address and ownership status of the residence. Complete the form and click the blue 'Save' button to continue.

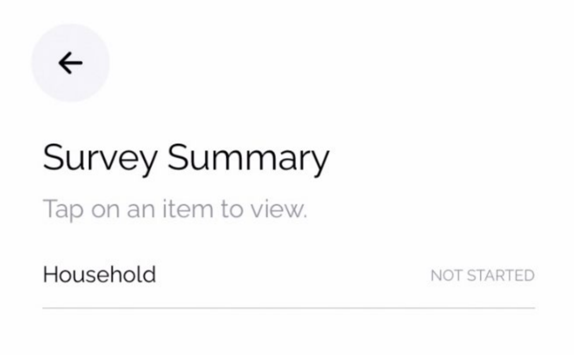


Figure 2.2.4 Recruitment survey summary screen

After you complete the Household Survey, two similar surveys labeled 'Members' and 'Vehicles' will appear. Complete the two new surveys ensuring that you list all vehicles and members of your household.

Figure 2.2.5 Recruitment survey submit button

After completing all three portions of the recruitment survey, press the blue 'Submit' button at the bottom portion of the screen to submit your survey. Your recruitment survey will then be reviewed by the HTS@TN team.

2.3 User Login

To log in to the HTS@TN survey, simply launch the application and enter your username and password in the respective fields. Afterwards, click the blue "Sign In" button.

2.4 Signing Out

To sign out of the HTS@TN survey, navigate to the Settings menu from your home dashboard. Afterwards, select the red 'Sign Out" option at the bottom of the list.

3. Settings

3.1 Profile Settings

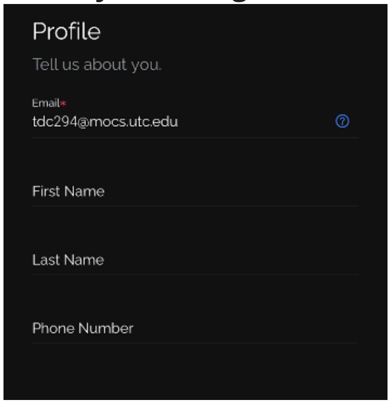


Figure 3.1 Profile settings page.

Under the Profile tab, users can view their email and edit their first name, last name, and phone number.

3.2 Security Settings

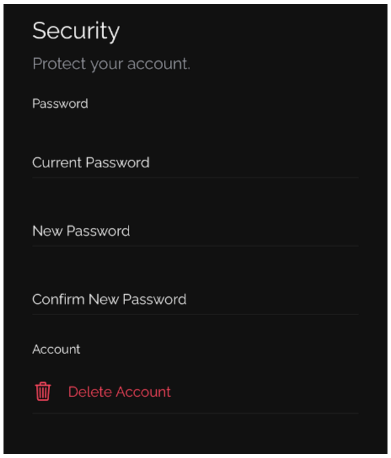


Figure 3.2 Security settings page

The Security tab provides users with a secure interface to change their password. Additionally, users can use the Security tab to delete their account if necessary.

3.3 Saved Address Settings

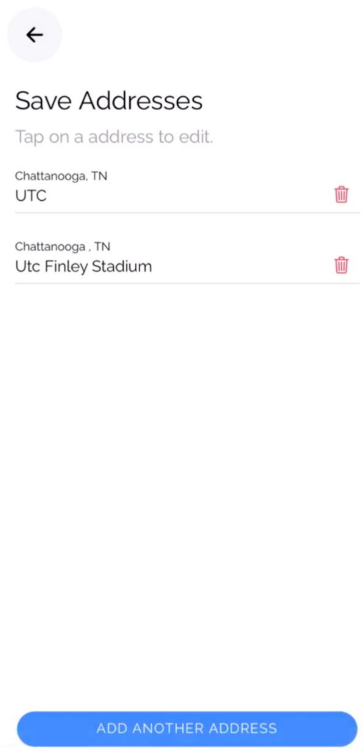


Figure 3.3 Saved Addresses screen.

The Saved Addresses tab provides users with a list of previously saved street addresses. Users can add addresses using the large blue ‘Add Another Address’ button at the bottom of the screen. Additionally, users can discard unneeded addresses using the red garbage can icon beside each individual location.

3.4 App Themes

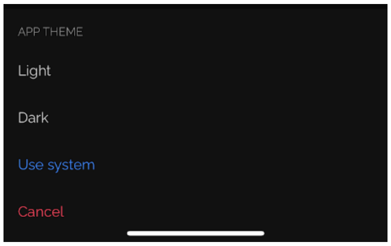


Figure 3.4 App theme selection pop-up

The App Theme setting allows users to choose between three theme choices: dark, light, and ‘use system,’ which defaults to the theme your device is set to.

3.5 Feedback Survey

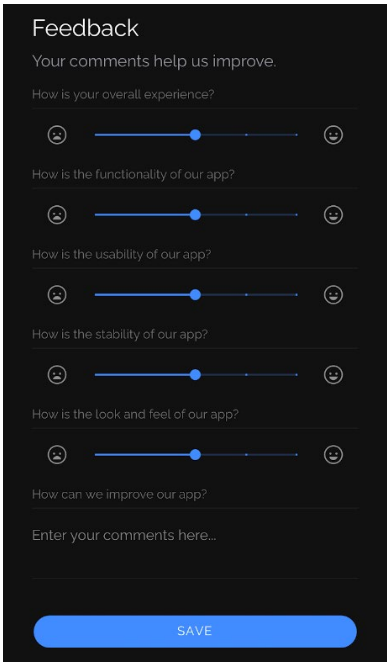


Figure 3.5 Feedback survey

The Feedback tab allows users to fill out a short questionnaire to provide quick feedback about their experience with the HTS@TN travel survey.

3.6 Help

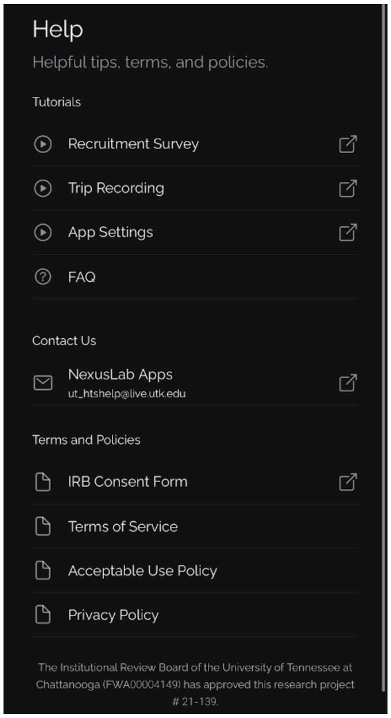


Figure 3.6 Help page

The Help tab provides users with an array of pre-recorded video tutorials describing the various functions of the HTS@TN app. Additionally, this tab provides the users a quick way to access all legal forms pertaining to the application. Finally, users can use this tab to directly contact the HTS@TN team for assistance.

4. Trip Logging

4.1 Tracking Trips via GPS

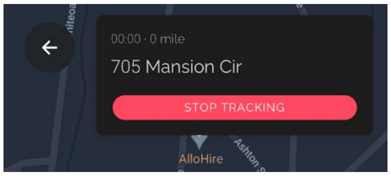


Figure 4.1.1 GPS tracking window

To track trips via GPS, start by pressing the blue plus button at the bottom-right corner of the home dashboard. Afterwards, select GPS tracking. The HTS@TN application will begin tracking your trip and you will be free to put your phone down.

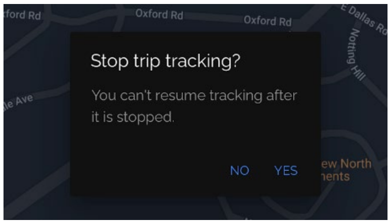


Figure 4.1.1 Stop trip tracking popup

Once your trip is finished, reopen the app and select the red 'Stop Tracking' button. This will open a form that allows you to select your medium of transport and trip purpose. Once finished, the trip will successfully be logged.

4.2 Tracking Trips via Manual Entry

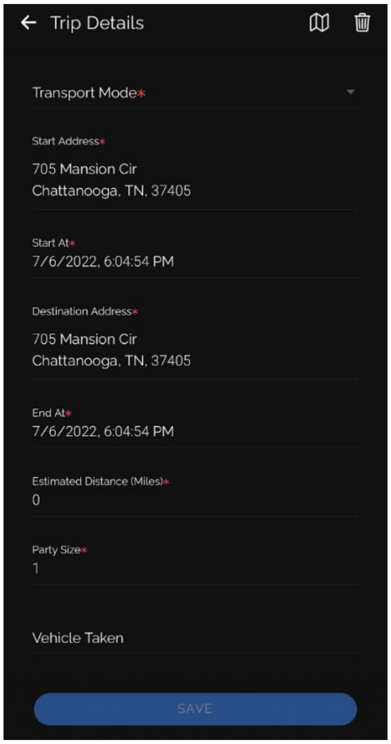


Figure 4.2 Manual trip entry window

If you are unable to use GPS or forgot to track your trip, don't worry; HTS@TN allows you to manually enter trip data. Firstly, press the blue plus button at the bottom-right corner of the home dashboard. Afterwards, select manual entry. This will open the HTS@TN manual trip form.

To complete the form, simply provide the requested information about your trip. Once this is complete, press the blue "save" button and your trip will be successfully logged.

Appendix I HTS@TN Web Dashboard User Manual

1. Dashboard Access

Users with the role of administrator can access the HTS@TN web-based dashboard at the provided URL.

1.1 Dashboard Login

To log in to the HTS@TN dashboard, access the URL and enter your username and password created in the HTS@TN application in the respective fields. Afterwards, click the “Sign In” button.

1.2 Signing Out

To sign out of the HTS@TN dashboard, navigate to the email address at the top of the dashboard, then click the email address to sign out.

2. User Management

2.1 User Information

Figure I-1 Dashboard Options

In order to see a list of users within the dashboard, click on the Users tab at the top of the dashboard, next to the HTS/Dashboard Logo.

2.2 All Users

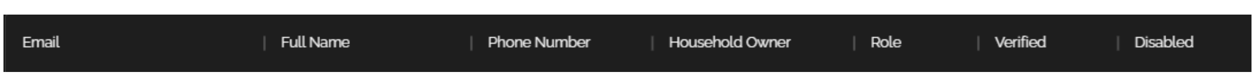


Figure I-2 List of User Information

Under the User tab, a variety of categories to sort all users are presented, namely the Email, Full Name, Phone Number, Household Owner, Role (User/Admin/Other), if the account is Verified/Disabled, the referral code used at registration, and the date of registration.

2.3 Filter All Users

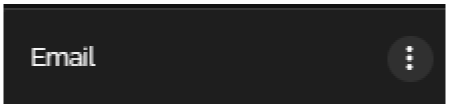


Figure I-3 Example of category/menu option

Filtering and sorting are available for all user categories. To sort in ascending or descending order (Numerically or Alphabetically) simply click on the category at the top or select the 3 dots next to the category after highlighting the category name. You can then manually sort by ascending or descending, or select the filter option, which allows for filtering out the list by entering a specific value into the filer menu that appears.

2.4 User Details
A view of the user details including the user categories, as well as the associated household and member ids, as well as the user's trips, saved addresses, and feedback can be found.

3. Data Management
3.1 Trips

Figure I-4 Data Menu Tab

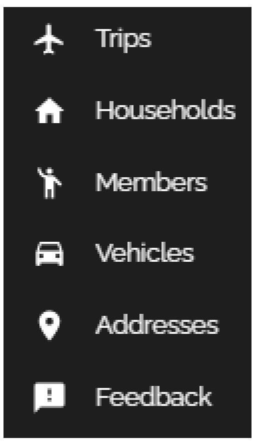


Figure I-5 Data Tab Categories

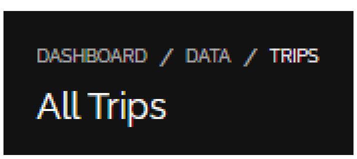


Figure I-6 Trip Tab Identifier

Trip data is available under the data tab of the dashboard, located at the top of the website next to the Users tab. Trip information is separated into several categories, including the start and end times, purpose for the trip, transportation type, start/end address/city/state/postal code, and when the trip was created.

3.2 Households

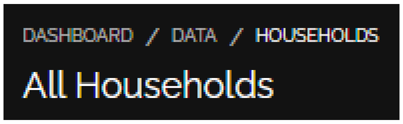


Figure I-7 Household Tab Identifier

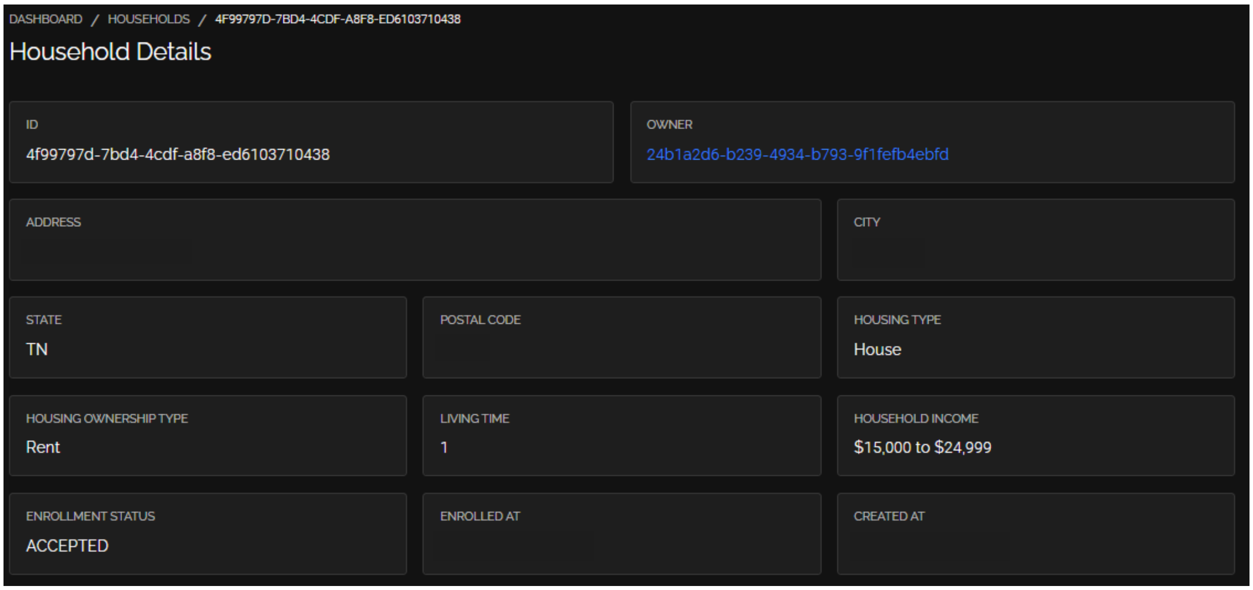


Figure I-8 Household Information

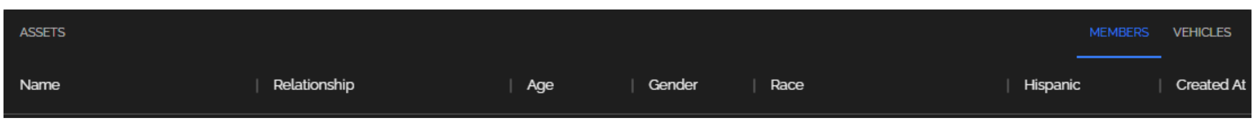


Figure I-9 Member Information

Household data is available under the data tab of the dashboard, located at the top of the website next to the Users tab. Household information is separated into several categories, including the household address, city, state and postal code, as well as the enrollment status (submitted, rejected, accepted, and under review), enrollment time, and when the household was created. Figures I-8 and I-9 showcase the information for each household, including the members of the household and the vehicles associated with that household.

3.2.1 Enrollment Status

Figure I-10 Enrollment Status Menu

The enrollment status of the household can be modified by clicking on any of the households available in the list, and then selecting the appropriate designation for the household from the dropdown menu as seen in Figure I-10.

3.3 Members

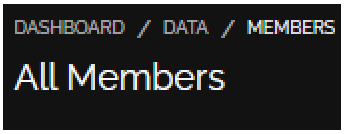


Figure I-11 Member Tab Identifier

Member data is available under the data tab of the dashboard, located at the top of the website next to the Users tab. Member information is separated into several categories, including member name, relationship to the household owner, age, gender, race/ethnicity, and when the member was created.

3.4 Vehicles

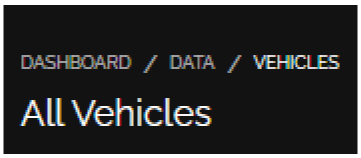


Figure I-12 Vehicle Tab Identifier

Vehicle data is available under the data tab of the dashboard, located at the top of the website next to the Users tab. Vehicle information is separated into several categories, including the vehicle's year, make, model, type, color, fuel type, and when the vehicle was added.

3.5 Addresses

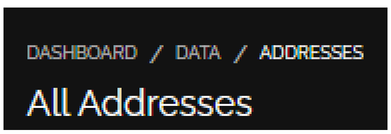


Figure I-13 Address Tab Identifier

Address data is available under the data tab of the dashboard, located at the top of the website next to the Users tab. Address information is separated into several categories, including the household owner name, the address/city/state/postal code, and when the address was added.

3.6 Feedback

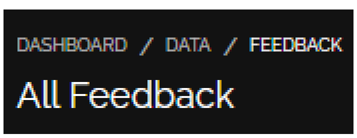


Figure I-14 Feedback Tab Identifier

Feedback data is available under the data tab of the dashboard, located at the top of the website next to the Users tab. Feedback information is separated into several categories, including the overall rating, functionality rating, usability rating, stability rating, the look and feel rating, as well as any additional comments made by the user.

3.7 Filter All Users

Similar to user information, filtering and sorting are available for all data categories. To sort in ascending or descending order (Numerically or Alphabetically) simply click on the category at the top or select the 3 dots next to the category after highlighting the category name. You can then manually sort by ascending or descending, or select the filter option, which allows for filtering out the list by entering a specific value into the filer menu that appears.

4. Additional Features

4.1 Dark Mode

Figure I-15 Dark Mode Toggle

A dark mode/light mode toggle is also available for users who wish to change the view of the dashboard. This toggle is located next to the user email at the top right of the dashboard tab.

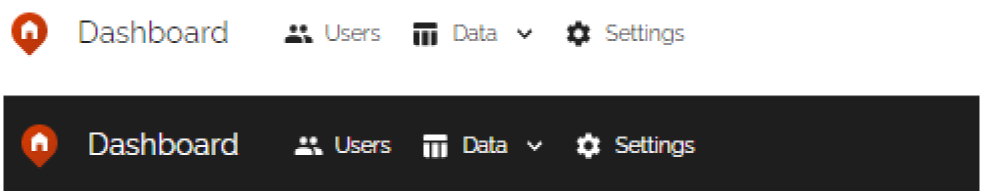


Figure I-16 Light Mode vs. Dark Mode

4.2 Website Settings

A settings menu is available, that allows for customization of public/private registration restrictions, when the website is available to non-admin users, contact information, and how long surveys are available to the user. Furthermore, a list of configurable URLs is available, with links to various important details, such as the application tutorial. Note: Many these settings are team specific, i.e. some configurations may need to be modified for use by different managing teams depending on who is operating the web application.

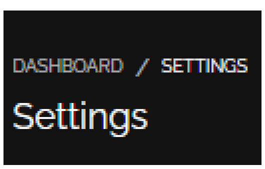


Figure I-17 Settings Menu