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16. Abstract Current and reliable data on traffic movements play a key role in transportation planning, modeling, and air quality analysis. Traditional travel surveys conducted via paper-and-pencil or computer-aided are costly, time consuming, and labor intensive for survey conductors; and place significant burden to the survey participants. Furthermore the accuracy and completeness are susceptible to participants' after-fact memory. On the other hand, smartphones are an integral part of daily life for many people in the world today. According to the Pew Internet & American Life Project's survey, in May 2011, 83% of U.S. adults have a cell phone and 42% of them own a smartphone. Many people today interact with their cell phones constantly to some degree through checking messages or emails, playing games, and talking. Smartphone applications have a great potential to lower the costs, reduce the burden, and increase the accuracy and completeness of travel surveys. This project evaluated existing smartphone applications for conducting travel surveys. The project compiled a list of the pioneering smartphone travel survey efforts and lessons learned, compared them, and analyzed their applicability to serve TxDOT survey needs. The project identified and installed a list of smartphone travel survey applications to thoroughly evaluate and compare their capabilities. The project summarized and classified the data elements collected by TxDOT surveys and built a prototype smartphone household survey app to validate that all the survey data can be collected using smartphones. The project discussed the opportunities and challenges in fully realizing the potential of using smartphone applications for travel surveys.					
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Evaluation of Existing Smartphone Applications and Data Needs for Travel Surveys

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DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the FHWA or TxDOT. This report does not constitute a standard, specification, or regulation.

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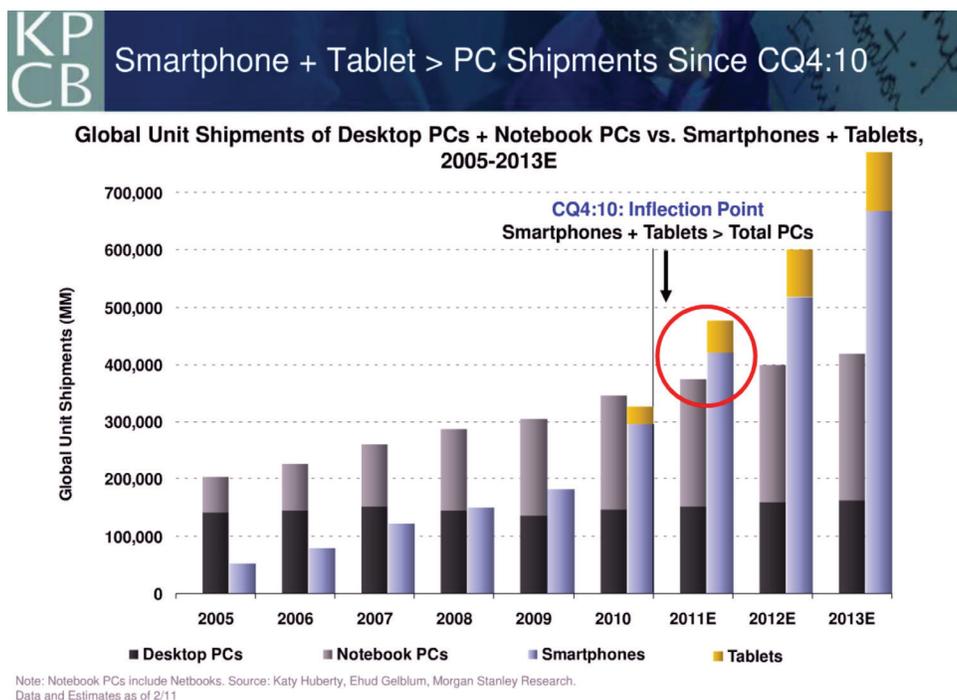
OVERVIEW

INTRODUCTION

Current and reliable data on traffic movements play a key role in transportation planning, modeling, and air quality analysis. Traditional travel surveys were conducted via paper and pencil, which are costly, time consuming, and labor intensive for surveyors as well as place a significant burden on participants. Furthermore, the accuracy and completeness of surveys are susceptible to participants' after-fact memory.

The smartphone market is burgeoning. According to the Pew Internet and American Life Project's survey in May 2011, 83 percent of U.S. adults have a cell phone, and 42 percent of them own a smartphone. In the first quarter of 2011, the shipments of smartphones and tablets surpassed desktop PCs and notebooks for the first time. Additionally, many of these smartphone users are mobile Internet users. In the U.S., the 3G penetration is 47 percent with a year-to-year growth of 27 percent in quarter three of 2010.

Figure 1. Shipment of Desktop PCs + Notebooks PCs vs. Smartphones + Tablets.



Many people today interact with their cell phones constantly to some degree through checking messages or emails, playing games, and talking with people. Smartphone applications have a great potential to lower the costs, reduce the burdens, and increase the accuracy and completeness of travel surveys.

The objective of this project is to evaluate existing smartphone applications for conducting travel surveys. To achieve the main objective of evaluating existing smartphone applications for travel survey purposes, we have devised a detailed work plan. A summary of the tasks are provided as follows:

- Task 1 - **Review of Smartphone Travel Survey Efforts:** review the existing smartphone travel survey efforts across the country and elsewhere in the world;
- Task 2 - **Texas Travel Survey Practice:** examine current travel survey practice in Texas;
- Task 3 - **Evaluating Existing Applications:** evaluate current travel survey application capabilities;
- Task 4 - **Classification of Data Elements in TxDOT Travel Surveys:** classify data elements collected by TxDOT and feasibility to conduct them using smartphones applications;
- Task 5 - **Opportunities and Challenges:** identify the potential and problems in using smartphones for travel survey;

REVIEW OF SMARTPHONE TRAVEL SURVEY EFFORTS

INTRODUCTION

The Texas Department of Transportation (TxDOT) conducted the first household travel survey (HTS) in the 1970s. Since then, TxDOT has continuously funded travel surveys to improve transportation planning and the travel demand models for the 25 districts around the state. A typical household travel survey needs to collect data on household activities, type of activities, and activity purpose, as well as modes of travel, type of vehicle, and departure and arrival time of travel. Traditional methods, such as paper and pencil based, are time consuming and place a heavy burden on both surveyors and participants. Many scientists and transportation departments have been endeavoring to reduce the cost and burden of travel surveys and improve the accuracy of data collection.

New technologies and advanced electronic products are continuing to be available with lower costs and higher data accuracy. In Texas, the Global Positioning System (GPS) was first used to supplement data collection for household travel surveys in Austin in 1998 (1). GPS-based data collection can achieve lower costs and burdens on participants and higher accuracy of data. However, some inevitable disadvantages have to be taken into consideration, such as comfort level of users who operate new technologies, GPS distribution/installation, and signal loss of GPS. Recently, with more embedded sensing modalities including GPS, accelerometers, microphones, and cameras, mobile phones or smartphones have become an appealing method for travel survey data collection (2). With customized applications, smartphones can detect speed, location, and departing and arriving time, and store all the data automatically when participants run a travel survey application. Thus, smartphones serve as a less burdensome and more convenient method and will play a major role in travel surveys in years to come.

THE EVOLUTION OF DATA COLLECTION OF TRAVEL SURVEYS

Before GPS was used for travel surveys, the main way to collect travel information data was self-reporting in the format of travel diaries. The modified travel diary survey was first conducted in the late 1970s. A diary is a booklet designed by Socialdata in Germany that was

introduced into the United States to serve the region surveys in Detroit and Honolulu in the early 1980s (3). Traditionally, surveyors randomly recruited household samples by calling and mailing out travel diaries to candidate household members. The participants were asked for their trip origin and destination of the routes they had taken for the day. Before the use of travel diaries, most household travel surveys were conducted through face-to-face interviews, which required participants to recall their previous trips.

Three main methods used for data collection, aside from the paper-and-pencil method, have used computers to help with data storage and collection: computer-assisted telephone interviewing (CATI), computer-assisted personal interviewing (CAPI), and computer-assisted self-interviewing (CASI). The oldest self-report is CATI, starting in the 1970s.

Originally, CATI needed two servers to support all the operations, one of which worked as a database to support data storage, such as file and data logs, and the other one to manage telephone lines, such as dial out and voice. A terminal helped surveyors when they were working over the phone with participants. Surveyors asked questions from terminal screens, and once they received answers from participants, they typed the results into the terminals where they were. Surveyors had to select participants from target regions and schedule time to call them, which was time consuming and costly. If either of the two servers broke down, the interview had to quit until the system recovered. Moreover, if a selected participant forgot to report the travel data, the missing data reports could result in lower data reliability. Now, although CATI does not completely support travel surveys, CATI is a preferred method for retrieving data in a GPS-based HTS.

CAPI became a new mode to collect data in the late 1980s when portable devices emerged. CAPI has some similarities with CATI, but the main difference is that CAPI requires talking to participants face-to-face. Within an interview, a surveyor types trip information from participants into portable devices, such as laptops. After interviews, data is sent to a central computer for storage. It is difficult to coordinate the schedule between surveyors and participants.

CASI is similar to CAPI (4). They both use portable devices to collect and store data. The main difference is that CAPI is conducted by surveyors, whereas CASI is conducted by participants themselves. With self-reporting, participants need to recall and submit their trip time, location,

origin, and destination. Many participants do not remember the exact time and location of each trip, which contributes to low levels of data accuracy. The under-reporting rate of self-reported-based household travel surveys conducted in the U.S. is about 20–25 percent (5).

TRAVEL DATA COLLECTION BY GPS

As a supplement or alternative method, GPS-based travel surveys have been evaluated by numerous research studies. The main advantage is that GPS can provide higher accuracy of spatial and temporal data. GPS units can automatically capture most data required by travel surveys including route origin, destination, speed, location, departure and arrival time, and distance. As a data collection method, GPS has several advantages. First of all, if a GPS signal is available, spatial and temporal data information can be collected precisely and in fine granularity (e.g., exact longitude and latitude in second by second). Secondly, data is collected continuously and digitally, reducing the burden of surveyors and participants and under-reporting.

GPS-based research methods on travel surveys are generally divided into two categories: interactive and passive modes (6). The interactive mode requires inputs of travel information from participants, whereas the passive mode works without any interaction from participants. GPS units are synchronously triggered when drivers start a trip, and automatically save the records when a trip ends. Early GPS-based travel surveys are interactive and in-vehicle GPS based. As a result, only vehicle-based data can be collected; other modes, such as walking, bicycling, and public transportation cannot be captured by in-vehicle GPS.

Table 1 lists the main GPS-based household travel survey reports and research on GPS-based data collection for travel surveys. The work that has been conducted in the last 12 years has seen the trend of using GPS as a data supplement for large-scale collection.

Table 1. List of Projects Using GPS on Travel Surveys.

	Sample and (GPS) Size	Duration (Travel Data Record)	Tool	Findings
2008–2009 Jefferson-Orange-Hardin Regional Transportation Study Household Travel Survey Summary (7)	1,666	The school year in fall 2008 to spring 2009 (NA)	Travel diary with GPS data collection	
2000–2001 California Statewide Household Travel Survey (8)	17,040 (292)	Oct. 2000 to Dec. 2001 (1 or 2 day)	CATI and GPS/PDA	1) Data information in temporal and spatial is high accuracy 2) The input of travel mode, purpose, and occupancy is needed
GPS-Based Household Interview Survey for the Cincinnati, Ohio, Region (9)	5,000 (2,608)	Aug. 2009 to Aug. 2010 (3 day)	Handheld GPS	1) Data accuracy in temporal and spatial is higher 2) The GPS-based method has superiority in data collection 3) It is a passive input survey
Use of Electronic Travel Diaries and Vehicle Instrumentation Packages in the Year 2000 Atlanta Regional Household Travel Survey (subsample test) (10)	About 1,200 (1,185)	In the fall of 2000 to the spring 2001 (3–4 day)	GPS, GPS/PDA	The data accuracy is improved
Lexington Area Travel Data Collection Test (11)	100 (85)	Sep. 1996 to Dec. 1996 (At least 3 days per week)	In-vehicle GPS/PDA CATI	1) GPS with PDA is feasible 2) GPS technology can improve the quality of data
Chicago Regional Household Travel Inventory (12)	14,390 (500)	Jan. 2007 to Mar. 2008 (1–2 days)	GPS supplement and prompted recall	
Can Using GPS Improve Trip Reporting? (13)	100 (85)	In fall 1996	CASI GPS/PDA	1) Trips may be missed due to signal loss 2) Using computer technology in multiple days can make burden
Applications of New Technologies in Travel Surveys (14)	NA	NA	NA	GPS logging devices can be used for collecting multi-day data as a supplement
Household Travel Surveys: Where Are We Going (3)?	(Review) NA	NA	NA	Extensive use of GPS improves accuracy and completeness
Assessing the Accuracy of the Sydney Household Travel Survey with GPS (5)	70	Feb. 2004 to Sep. 2004 (1 day)	GPS prompt call	GPS can be successfully used as a supplement of a travel diary
Elimination of the Travel Diary: Experiment to Derive Trip (1)	30	Mar. 23 to Apr. 28 in 2000 (3 days)	GPS and travel diary	GPS can derive travel purpose, but the accuracy needs to be improved
Continuous Improvement in Regional Household Travel Surveys (15)	1,187 (173)	Apr. 19 to July 8, 2010	GPS, CATI, CASI	1) Continuous improvement process is feasible 2) Data information can be collected based on web page and geographic information system 3) New technology tools are needed to improve accuracy
GPS-Assisted Prompted Recall Household Travel Survey to Support Development of Advanced Travel Model in Jerusalem, Israel (16)	6,000 (3,000)	Mar. to Jun. 2010 NA	GPS, Travel Diary, and CATI	1) It is the first large-scale GPS used in travel survey outside the United States 2) GPS-assistance method is convenient for travel survey, and it can eliminate the under-report rate 3) Accuracy is satisfied 4) Acceptance rate is high
GPS as Data Collection Method for Travel Research (Netherlands)	151		GPS	1) The device monitors all the travel modes 2) Public transport trips are registered with a higher accuracy level than car trips
Wearable GPS Device as a Data Collection Method for Travel Research	2 Device loggers	Project year, 2006 in Sydney	GPS	1) Using the optional rules can identify the different trips and travel modes by a wearable GPS, but the optional rules should be fine tuning 2) Data loss due to a blocked signal

A GPS-based survey was first used and tested in 1996 under the Federal Highway Administration (FHWA) (11). The first GPS-based pilot with a personal digital assistant (PDA) was conducted in the Lexington, Kentucky area. The Lexington Area Metropolitan Planning Organization (Lexington MPO), the principal planning agency, recruited 100 households to test the feasibility of the GPS-based method for data collection. The project team developed a GPS equipment package comprising a handheld computer, a GPS receiver, Personal Travel Survey Software, a memory card, and a connecting cable. This equipment required participants to input trip purpose, mode, and occupancy, and then all travel information was stored on a memory card. Before the assigned travel day, GPS equipment packages were distributed and installed in candidate vehicles to record travel data. Travel mode, trip purpose, and occupancy had to be retrieved by CATI with travel diaries. After that, the project team conducted a recall survey to compare and validate the trip data from participants via GPS. From this pilot, the project team successfully captured higher-level second-by-second GPS data information with accuracy within 10–16 feet. This project team not only tested equipment to get GPS data but also received self-reported data by an estimated 85 out of 100 households. A follow-up project proved that the GPS method could reduce missing trips and achieve higher data accuracy. Though the researchers found that the GPS-based method alone could not completely support a travel survey, this method was still promising (13).

The main reasons leading to under reports are the length of trips, forgetting to report, and unimportance of trip information based on participants' judgment. The GPS-based method is thought to have a lower under-report rate. A project to evaluate the GPS data under-report rate was conducted by the University of Sydney (3). This experiment was designed to assess the accuracy of data collection with a focus on the under-report rate from GPS data collection. The researchers recruited 50 households to take GPS surveys and also assigned recall surveys to identify all households' trip purpose, mode, and occupancy. The CATI-based travel surveys under-report rate is 20–25 percent, and the GPS under-report rate is reported at 7 percent in the U.S. (3). In this study, the under-report rate was 7.4 percent. Although the under-report rate still exists, GPS as a data supplement for travel surveys and replacement for travel diaries is feasible.

Originally, a GPS was a unit installed into pilot vehicles, which means only vehicle data could be captured. With the availability of portable devices, researchers attempted to collect data for

different travel modes. From research in the Netherlands in 1997, PDA/GPS receivers were used to collect data from different modes (14). The project team developed PDA/GPS units that were assigned to 151 participants to capture trip data. Though researchers concluded that these portable units could be a potential method to monitor diverse travel mode data, the monitoring package weighed approximately up to 2 kg. They were too heavy for participants to carry, contributing to a low rate in acceptance.

Based on some prior proof-of-concept studies on under-reporting, travel modes, and accuracy of data collection using GPS, the GPS-based method started to be used as a supplement for data collection. In the year 2000, the Atlanta MPO Travel Survey collected and analyzed sufficient data to improve the travel demand model by in-vehicle GPS (10). To support data demand, the Georgia Institute of Technology developed three different instrumentation packages and randomly selected 1,200 households. GPS data was compared with the reported data from a large subset of participants to validate the accuracy of GPS data. This pilot validated that GPS with PDA equipment could work for household travel surveys with reliable accuracy.

Most GPS data collection needs participants to provide or input trip purpose, travel mode, and occupancy. To test whether GPS can be used alone for travel surveys rather than as a supplement, a comparison experiment was conducted by the Georgia Institute of Technology and GGeoStats Pty Ltd under Jean Wolf, Randall Guensler, and William Bachman in 2001 (1). This project team developed three in-vehicle GPS data loggers. Considering the existing features of equipment for the data collection, only vehicle trips were taken into account. The team invited 30 participants who were divided into two groups. The first group involved six participants who were assigned to test equipment installation and procedures, and the second group consisted of the remaining 24 participants who were distributed with both GPS loggers and paper diaries. Based on the data from the two groups, the project team implemented an algorithm to derive trip purpose with a land use analysis. This study concluded that GPS loggers to completely replace traditional approaches of data collection to capture trip information was feasible, and the benefits of passive GPS data collection were: 1) a reduction of burden and telephone interview length; 2) a reduction cost in telephone interview; 3) the extension of survey periods; 4) improvements in accuracy and completeness; 5) the collection of new travel data elements that could be evaluated.

According to the research on GPS-based travel surveys, two practical household travel surveys have used GPS for travel information collection. The first large-scale use of GPS for a household travel survey was conducted in 2000–2001 in California. This travel survey used both GPS and CATI to capture trip information, and GPS worked as a supplemental method for data collection. The researchers randomly recruited about 17,040 households throughout 58 districts from October 2000 to December 2001 and sent them paper diaries (8). In this survey, GPS captured date, time, latitude, longitude, speed, and altitude. The surveyors retrieved trip purpose, trip mode, and occupancy by CATI, and participants sent back their trip diaries to the agency office. Finally, the survey team combined paper diaries with GPS loggers to analyze the regional travel model and demand.

The other practical household travel survey was conducted in the Ohio Region. This survey used GPS as a passive method. It was the first full-scale GPS-only household travel survey (9). The first goal of the project was to investigate whether all travel data could be sufficiently detected by GPS alone, and the second goal was to validate if GPS could fully represent all data information from household travel surveys. This project recruited over 5,000 address-based households and lasted for 12 months, starting in August 2009. The GPS unit was portable and easy to carry. Thus, these GPS units were not only installed into vehicles but could also be carried in a pocket or purse. In other words, this unit could capture different travel mode data. For accuracy checks, a prompted recall survey was conducted to validate travel mode and purpose from GPS recordings. Finally, 601 households finished the prompted-recall surveys. This study proved full-scale use of GPS for travel data collection was feasible, and a high level of accuracy was achieved in this research.

GPS-based travel surveys as a convenient method to collect trip data has many advantages compared with traditional methods. The GPS method can save time, decrease labor, and lower costs. Moreover, it produces more reliable and high-resolution temporal and spatial data. Most of the participants are able to operate the units. However, if the signal is weak or lost when participants move to urban cities or canyon areas, GPS cannot detect any travel information.

TRAVEL DATA COLLECTION BY SMARTPHONE

Today, smartphones have many embedded sensors, including a GPS, microphone, digital compass, and accelerometer. Using smartphone applications together with an embedded GPS to collect travel survey data is a natural advancement to the GPS-based travel survey method. In addition, an accelerometer is able to monitor physical activity to help recognize the travel mode (17). Currently, although there are no large-scale household travel surveys using smartphones, several pilot studies have investigated smartphones as a data collection tool and found several advantages (18). First, smartphones are commonly carried by participants every day, which reduces the case that participants will forget to take the devices on survey day. Second, most of the recruited participants are familiar with the operations of smartphones, and they can conveniently download and install applications to their smartphones to take surveys. Thus, it is not necessary to perform a training for the participants on how to use the device to collect travel information. Third, the cost of distribution of devices and the burden on both surveyors and participants can largely be decreased. Some GPS-based household travel surveys use customized GPS units to perform data collection, so before the survey day, these units are supposed to be distributed to participants. For smartphone surveys, participants own smartphones already, so the equipment purchase cost is eliminated. Additionally, most operating systems running on smartphones are Android and iPhone Operating System (iOS), so applications for travel surveys can easily be developed and published in the Apple Store and Android Market. Table 2 is a list of published applications of travel surveys running on smartphones.

Table 2. List of Smartphone Applications (Apps) for Travel Surveys.

	Developer	Web Link	System	Functions
CycleTracks	San Francisco County Transportation Authority (SFCTA)	http://www.sfcta.org/content/view/1159/556/	iOS and Android	1) Record bicycle trip routes and time 2) Send data to SFCTA after trips 3) Display Ride map 4) Collect trip purpose, route, and time
AggieTrack	Texas A&M University and Bryan-College Station	http://android.appk.co/aggietrack-105-a15104.html	Android	1) Collect basic personal information 2) Collect spatial and temporal data
RouteScout	NuStats	http://www.nustats.com/webandmobileapps/wma-RouteScout.html	iOS and Android	1) Real-time GPS data log 2) Record activity information and submit trip data
PaceLogger	NuStats	https://itunes.apple.com/us/app/pacelogger/id387792895?mt=8 https://play.google.com/store/apps/details?id=src.com.nustats.pacelogger&hl=en	iOS and Android	The same as CycleTracks
FM Survey	Singapore-MIT Alliance for Research and Technology	https://play.google.com/store/apps/details?id=edu.mit.smart.fmsurvey.android&feature=search_result#?t=W251bGwsMSwyLDEsImVkdS5taXQuc21hcnQuZm1zdXJ2ZXkuYW5kcm9pZCJd	Android	1) Collect spatial and temporal data 2) Collect travel mode
GPS-ATD Survey	AHMCT	https://play.google.com/store/apps/details?id=edu.ucdavis.ahmct.atd.android.atdAndroid&hl=en	Android	1) Collect travel mode 2) Collect profile data 3) Driver safety warning screen

CycleTracks was developed by the San Francisco County Transportation Authority (SFCTA) to record bicycle trip information, such as trip routes, times, and purposes, by smartphone. This application can also display the map of users' routes, which help transportation planners to assess the use of bicycles in the community. At the end of each trip, all trip data information is sent to SFCTA. The functionality of PaceLogger is the same as CycleTracks because CycleTracks is open source.

AggieTrack is an application from the Texas A&M University URSC 493 Transportation Research Project Travel Survey. This application is published on the Android Market and runs only on the Android system. This application displays users' preference with a pull-down interface to collect trip information.

RouteScout was developed by NuStats to collect real-time GPS logging and activity logging for travel surveys. It is available on both iOS and Android systems. Users need to initiate the GPS data logging, and after the trip, they submit their trip data.

The Further Mobility (FM) Survey application is a part of the household travel survey funded by the Future Urban Mobility group in the Singapore-MIT Alliance for Research and Technology. The main goal of the survey is to collect data on Singaporean households' travel information.

The GPS Automated Travel Diary (GPS-ATD) Survey is published by Advanced Highway Maintenance and Construction Technology (AHMCT). It is intended for minimizing the burden of users participating in household travel surveys. This application can provide reliable data accuracy with lower cost.

Most of the travel survey applications in Table 2 can run both the iOS and Android systems; however, developers prefer Android because of its open source. Applications can perform data recording with GPS sensors in smartphones, and interfaces are concise and designed with pull-down displays. Additionally, most travel data, for example, travel time, speed, and location, can be captured with reliable accuracy.

Early research on GPS-based methods evaluated their feasibility for household travel surveys. Similarly, smartphones can capture spatial and temporal activity data second-by-second using embedded GPS sensors. Collecting data using smartphones is more convenient and has a lower

cost, making it possible to conduct longer travel surveys. Participants just need to run the applications on days of travel. It is not necessary to administrate GPS devices for installation. After trips, data is automatically sent to a central sever if the Internet is connected. However, constantly turning on GPS is very energy consuming. Thus, to save battery power, methods have been developed to reduce the frequency of GPS data updates, and GPS is automatically switched off after trips. Table 3 lists existing research on using smartphone data collection in travel surveys.

Table 3. List of Research on Smartphone Travel Surveys.

	Applications	Type of Activity	System	Way of Data Upload	Data Elements	Burden	Bias	Findings
A Strategy on How to Utilize Smartphones for Automatically Reconstructing Trips in Travel Surveys (19)		NA	Android	NA	Spatial and temporal data	Less	NA	1) The accuracy of data is content 2) Further on acceleration signals for stop detection and separation.
GPS Mobile Phone-Based Activity Diary Survey (20)		Activity Based	NA	Bunch transmission to a central server	Spatial and temporal data	Less and depends on some characteristics	NA	1) Convenience. 2) Battery consumption affected travel choice.
A Study of the Effectiveness of a Household Travel Survey Using GPS-Equipment Cell Phones and a Web Diary Through a Comparative Study with a Paper Based Travel Survey (21)		HTS	NA	Bunch transmission to a central server	Spatial and temporal data	Less but dependence on conditions	NA	Improve data precision.
Smartphone-Based Travel Experience Sampling and Behavior Intervention (22)	UbiActive	Activity Based	Android	Bunch transmission to a central server	Activity information	Less	NA	Successfully monitor travel activities.
Behavior Analysis of Choice of Daily Route with Data from Global Positioning System (23)		Activity Based	Symbian or Android	Real time	Positioning points	NA	NA	Further issue to reduce travel data error.
Using Smartphone to Collect Bicycle Travel Data in Texas (24)	CycleTracks	Bicycle Activity	iOS and Android	NA	Spatial and temporal data	NA	NA	Usefulness of smartphone with GPS to collect data.
Using GPS-enabled Cell Phones to Track the Travel Patterns of Adolescents (25)		Activity Based	NA	Bunch transmission to a central server	Location data	NA	NA	Ideal modality of monitoring location and patterns.

Based on previous pilot tests, mobile applications can steadily run on smartphones with reliable accuracy of data. Most of the projects in Table 3 attained real-time data and allowed data to transmit to a server for data storage, which can save space on participants' smartphones. Due to the limitation of battery power, applications need to turn off GPS sensors automatically or remind participants to turn the application off when not traveling. Bias inevitably lies within participant recruitment. For example, participants should be familiar with operations of smartphones, and they could be technology preferences. Males are more likely than females to use smartphones, and there are more young people using smartphone than elders. How to deal with sample bias is still a research issue.

Two earlier research projects on GPS-enabled cell phone use for travel surveys (21) and GPS use for travel diaries (20) used a similar experiment method to test mobile phone applications to obtain trip data information in Japan. The trip data was captured in December 2004 with 31 participants. Participants were required to switch on and off applications to trigger a trip, and select trip modes, occupancy, and location after trips. All data was transmitted to a central server. The location was sampled every 30 seconds in order to save battery life. Battery capacity generally drains out within 3 hours if GPS is turned on. Data errors can be corrected during the data process. Research found that as a novel method to collect trip data, smartphones were less burdensome than other methods, and data accuracy was reliable as well. However, these two research projects did not take bias into consideration, and the pilot was only assigned to the participants who had mobile phones with embedded GPS sensors to install the applications. The mobile phone systems in 2004 were not as convenient as current ones. Though the limitations exist in the research, the use of mobile phones as a method of data collection proved promising.

In another project, researchers designed an experiment to test a strategy for conducting travel surveys using smartphones (19). Because people with preference to intelligent products are more likely to use smartphone-based survey, the smartphone survey was served as a supplemental data collection to avoid sample bias. Trip data information was generated from 14 people over two months, and the pilot obtained 266 hours of trip data in the city of Vienna, Austria, and surrounding areas. The application was designed on the Android system. When travel mode was changed, the application could record it synchronically by using an accelerometer with GPS (27). During data processing, the errors could be corrected. Researchers concluded that using

smartphones to capture trip data was feasible and found that the classification of travel mode achieved satisfied accuracy. They also noted that due to inevitable bias, the smartphone-based method cannot cover all demographics, but smartphone collection can serve as a data supplement.

Smartphones also served as a method of trip data collection in some other projects. In one study focused on travel route choice analysis with GPS data, the research team collected 26 students' trip data from the University of Cagliari during 2 weeks in 2009 (23). Researchers installed the application that was developed by the University of Cagliari on Symbian and Android smartphones. The application could monitor individual routes and related travel data every 5 seconds. Instead of batch uploading data after trip surveys, they uploaded travel data in real-time. To save battery power, GPS could be switched off when participants ended their trip, and the participants were reminded by the application. Another research study used the UbiActive application on smartphones to receive real-time travel data information every 30 seconds to save battery life (22). A total of 30 persons having Android smartphones participated in this survey over 2 weeks. After each individual trip, the data was sent to a server for storage. A third research study used a smartphone application to track trip information and analyze travel patterns of adolescents. Fifteen female adolescents took the survey with BlackBerry smartphones. The survey lasted 7 days. Researchers concluded that the accuracy of smartphone-based method data collection is reliable (25).

Over 300 bicyclists provided about 3,600 route records in Austin between May 1 and October 31, 2011 (24). The participants installed an application developed by SFCTA and transmitted trip data to an SFCTA server when they clicked the end button. If the battery was lower than 10 percent of capacity, the application turned off automatically. The report summarized the output of the data collection using CycleTracks in order to validate the usefulness of captured bicycle route information. Moreover, this report provided rich research information on smartphone-based data collection.

Some recent research focused on improving the smartphone-based household survey application development. Research by the California Department of Transportation (Caltrans) relied on a deliverable app called GPS-ATD on Google Play for participants to install and test the

performance (26). Eighty participants were invited to join the test project on 27 different Android devices and report the bugs of GPS-ATD. In this project, GPS-ATD is viable to be used in a travel survey, and the beta data collection system demonstrated its feasibility. The researchers believe GPS-ATD can be a supplement tool for a pencil-and-paper survey. In terms of battery life, the devices for testing are able to run GPS-ATD for 6 hours and more. Some further tasks the researchers considered were running the app on multiple platforms such as iOS and Windows to cover more participants, app optimization to reduce the burden on participants, low consumption power via reducing the updates of GPS, and more passive input.

FM Survey was developed in the Republic of Singapore to serve as a household travel survey (27). Singapore's traveling system consists of a smartphone application, activity, and website to collect travel and demographic information in four stages. All participants were required to register with their basic demographic information and received a pre-survey in order to detail household information. When they completed the activity diaries, they needed to log on the website to modify the data. To exit the survey, they are required to provide feedback and additional household information if needed. This project concluded that smartphone-based travel surveys through FM Survey could be feasible in Singapore, and the additional issues could be focused on for improvement of the app.

In conclusion, the methods of travel data collection for household travel surveys mainly include paper based, CATI, CAPI, CASI, GPS, and smartphones with applications. Traditionally, before GPS was used for data collection, methods of data collection were time consuming, labor intensive, and costly as well as produced unsatisfactory data accuracy.

The GPS-based method provides more precise data information especially on temporal and spatial data. Early GPS units were used for data collection with the help of PDAs, and trip data was saved into memory cards in PDAs. Before the assigned survey day, the devices needed to be distributed to participants, and the recruited households needed to take a tutorial on operations of the GPS/PDA, which was possibly difficult for some participants. Thus, most early GPS-based methods worked as a supplement of data collection. The first full-scale use of GPS for data collection was in the year 2010. The GPS devices used in that first project became portable and smarter. The device was conveniently carried in by hand, or in a purse or pocket. Researchers

demonstrated that the accuracy of data from GPS is reliable; however, if the GPS signal is weak when users are in urban areas or canyons, the GPS cannot capture satisfactory travel data.

The smartphone-based method is the latest data collection method and works by utilizing applications on smartphones with GPS-embedded sensors; this method provides an enhanced mode for household travel surveys. In a smartphone-based HTS, participants use their devices instead of assigned GPS units. Compared with previous devices used, participants are more familiar with operations on their smartphones. Thus, smartphone-based data collection has the potential to meet household travel survey needs in the near future.

TEXAS TRAVEL SURVEY PRACTICE

INTRODUCTION

TxDOT has been continuously conducting household travel surveys for the past few decades to construct travel demand models for transportation planning. In 1985, the Dallas/Ft. Worth–North Central Texas Council of Governments and Houston–Galveston Area Council of Governments conducted the first household travel survey in Texas since 1970 (28). TxDOT conducted not only household travel surveys but also workplace and external surveys in Texarkana in 1989. The next year, 1990, TxDOT funded more travel surveys in five urban areas in Texas.

In general, the process of a travel survey includes survey planning, survey design, field implementation, data preparation, and data analysis. The travel survey procedure has not been standardized, although considerable arguments in favor of standardization exist. An online travel survey manual compiled by transportation survey researchers and professionals advocate for the standardization of the travel survey procedure for the obvious benefits of data sharing, data comparison, and cost reduction (29). TxDOT has been using specifications and guidelines for household travel surveys.

This section of the report describes the project task of looking into the TxDOT household survey process and discussing its level of standardization. The current practice in light of possible smartphone-based travel surveys will be discussed. This section also reviews a selected set of previous household travel surveys in Texas and summarizes the survey methods, data requirements, and data analysis.

This section first reviews and discusses how an HTS is conducted and common issues to be addressed in a typical HTS. It then reviews recent literature and reports on travel surveys in Texas. The section also compares the technical summaries of several recent HTSs conducted in the Waco, Lubbock, and Jefferson-Orange-Hardin Regional (JOHRTS) areas. It then discusses the level of standard of TxDOT using Household Activity Travel Survey Publication Specification No. 968-85-60.

HOUSEHOLD TRAVEL SURVEY OVERVIEW

Household Travel Survey Design Framework

Before conducting an HTS, survey planners need to identify the HTS framework as much as possible, which includes the goal of the HTS, type of HTS, data needed, survey method selection, sample recruitment, specific schedules for each task, project manager (PM), data quality control, and some other requirements. This framework sets the direction and methods of the HTS, which is very important in order to conduct a reliable travel survey. Typically, an HTS is conducted by vendors with 3 to 5 years of related travel survey experience. When designing the framework, constraints of an agency's time and budget will need to be taken into consideration (29).

Types of Household Travel Surveys

The choice of HTS type will affect the efforts of the HTS. Different HTSs require different types of data. Generally, an HTS is divided into three types: trip-based surveys, activity-based surveys, and time-use-based surveys (29). Trip-based surveys are used to directly collect people's trip information over some time period. The main items of data collection are the trips that households make. Activity-based surveys ask respondents to report activities and the trips that are generated by those activities. On one hand, respondents can remember activities better. On the other hand, this type of survey collects both trip information and activity information that are produced by these trips, so it introduces more burdens on the respondents. As a result, the response rate may decrease. Activity-based surveys were developed from traditional trip-based surveys. Time-use-based surveys record all activities for a given period of time even if some activities do not require travel. Thus, it has the most participation burden of the three types.

Data Needed

Data need is determined by the goal of the travel surveys. For example, some travel surveys are for trip-based travel demand models, while others focus on the activities of work and home or concerns about the impact to local infrastructure (29). A guide comprised of travel survey agency input on what data is necessary and how the data can be used for later analyses is recommended. With the initial design of a survey, travel planners are expected to understand the goal of the HTS, the data features that can impact the survey, the amount of data needed, and the data

source. Generally, data collection refers to the collection of trip information, activity information, vehicle information, and demographic information.

Sample Frame Recruitment

To initialize an HTS, travel survey planners need to decide on the unit of analysis of data, such as the overall travel-activity information from all the members living in the same household or an individual who has certain characteristics in a household, such as a student, employee, or retiree. Sampling households are supposed to proportionally represent the demographic distribution in the survey area as much as possible in order to avoid sampling bias. The most common sampling methods are address-based and telephone-based recruitment. In an address-based sampling, a database of the addresses of the targeted region is needed, and random sampling can be done on the database. There are two ways to perform telephone-based recruitment: random-digit-dialing (RDD) and sampling from telephone directories. The RDD approach starts with a list of telephone exchanges within the study area and generates random telephone numbers of the potential respondents to call. The other method needs a telephone directory, and random phone numbers are chosen from the directory. The first full-scale GPS-based HTS conducted in Ohio recruited household participants by using an address-based sample frame. An address-based sampling frame extracts the address information from the delivery sequence file (DSF) that is held by the United States Postal Service and contains each delivery point in the U.S.(30). Research centers can obtain the DSF from private vendors, and information in the DSF contains private information of households. Because of the existence of a large percentage of invalid telephone information, the address-based method can be more effective than the telephone-based sampling frame and can achieve considerably better data accuracy. In terms of response rates, address-based sampling frame by mail design is 40 percent higher than RDD (31).

Travel Survey Time

A typical HTS is conducted in school sessions—spring or fall—and during weekdays when travel behaviors from households are routine activities and represent the practical situation of transportation in the local area. The whole HTS project regularly lasts around one year starting

from survey design and ending at the production of a deliverable report. The data collection duration mostly ranges from one day to three days.

Historical Methods of HTS Data Collection and Tools

The primary activity of an HTS will be the orderly launching of the sampling household frame after sample households agree to participate. The early HTS trip data collection method was extremely simple and monotonous through a costly paper-and-pencil method where interviewers attained the data information at the participants' houses (32). Obviously, this method is not an effective and economical tool for data collection. With the advancement of technologies, diverse methods and tools are now used for HTS. In the 1970s, addresses of respondents who agreed to participate were recorded, and travel/activity diaries and prepaid envelopes to send back completed diaries were sent to these addresses (32). Later, CATI, CAPI, and CASI became common ways to retrieve trip information. CATI became the most widely used form of data retrieval and data quality control in HTSs. In addition to travel/trip diary collecting, GPS has been used for data collection in recent HTSs. In this method, GPS equipment is sent to participants before the survey day. This method enhances the level of data accuracy, especially in temporal-spatial data.

Smartphone-Based Method of HTS Data Collection

Smartphones are being introduced as a new method of travel data collection in some projects. Currently, this method is not widely practiced in the U.S. Several pilot projects on small scales are being conducted. The main benefits of using a smartphone for travel surveys include:

- Typically, the survey is conducted through an app that can be downloaded easily from an application store. This directly translates to reduced cost in distributing survey instruments.
- Data collection can be in near real-time through applications uploading data automatically. This results in reduced data collection efforts.
- Users can participate in a piece-meal fashion where a few items need to be entered each time through contextual awareness prompts. This leads to reduced and distributed user participation burden.

- Persuasive design can be incorporated into the survey app through gaming, gentle reminders, encouragement, contextual information, and user-centric design. This may lead to better participation rates and make it possible to conduct longitudinal travel surveys.
- Data entry errors can be corrected on the spot, which may lead to better accuracy.
- Smartphones are purchased, maintained, and charged by the user already, which leads to reduced survey costs.

There are also potential problems with smartphone-based surveys. The main ones include:

- Not everyone owns a smartphone. The survey results may lead to bias. Weighting techniques or complementary survey methods are needed to compensate the bias.
- An active data collection method through smartphones may still lead to attrition. It is still a burden for the users to actively take out their smartphone, open the app, and enter the required information before and after a trip. It is possible to reduce this effort by automating most of the process through using algorithms and geographical information systems. For example, one may be able to drive the trip purpose through geo-matching of the stops from GPS trajectories.
- Battery drainage is an issue if route information is needed. Map-matching on sparse GPS data can help to reduce the sampling frequency needed.

Pilot Survey of HTS

A pilot survey utilizes all facets of an HTS under a small subsample of households in order to test whether the survey design, procedure, and sample recruitment can achieve the expectation of the final results. It is not required to conduct a pilot HTS survey; however, a pilot survey has benefits from multiple aspects. In fact, quite a few projects have shown that conducting a pilot survey can result in changes and improvement in survey tools and procedure (33). A pilot survey can provide estimated cost of an HTS, enhance the questionnaires, provide a pretest training opportunity for interviewers, and provide guidance on effective sample size.

Bias of HTS

Bias can be introduced for many reasons including improper sampling methods, nonresponses, poor questions and survey instruments, and data entry errors. Bias can be classified into sample bias and nonresponse bias. Many steps in the HTS can produce bias. It is a challenging task to avoid bias.

In both address-based and RDD sampling frames, disproportionate population distribution within samples can lead to sample bias (34). For example, the rate of persons with high education is sampled more than those with low education, or the rate of higher income persons is more than lower income persons. A sample selection is supposed to be randomly determined or HTS vendors purchase a list of phone numbers that have been pre-screened to remove unnecessary phone numbers (35). If the bias is introduced by sampling, weighting on key characteristics of variables that represent household information, vehicle information, and trip information can be used to reduce bias.

Nonresponse is a serious concern and can introduce bias. It is difficult to retrieve all data from all participants due to the level of cooperation from people of different demographics. If the non-response characteristics are sharply different from the whole population, data bias will occur (36). Nonresponse is mainly due to conditions such as households being in the phone number list of the sampling but refusing to participate, and the household participants failing to complete the travel survey (34).

Previous analysis has shown that nonresponse individuals can be characterized by household members, ages, and ethnic groups. A higher response rate is primarily from participants under 30 years old and over the age of 69. Older people tend to be cooperative, but response rate is lower from older people if they are living alone. Additionally, lower response rate can also come from persons who live in costly housing located in a higher-density urban area. There is little difference in ethnic groups on response rate, e.g., between non-Hispanic whites and other groups (37). A few other studies documented similar results (38).

THE PRACTICE OF TXDOT

Recently, TxDOT has conducted HTSs in the areas of Waco, Lubbock, and JOHRTS. To facilitate the process of HTSs, TxDOT uses a detailed specification with requirements. The specification requires the survey vendors to be engaged in HTSs for a minimum of three years within the last five years and have an outstanding financial history.

The HTSs conducted in Texas have been mainly trip-based HTSs within a 24-hour time frame. Sample recruitment is based on sampling from a random telephone number list. Travel survey planners inform the households of selection to join the HTS by letters or postcards (34). Vendors can purchase the list of phone numbers. A sampling plan is based on the following household features: household size and household income (34). Incentives can be used as a method to improve the household response rate. GPS was first used for an HTS in 1997 in Austin, Texas. GPS is expected to be used in a passive data collection mode with a power supply within a subsample household set (1).

Before the assigned travel day, the sample households receive a reminder call to take the HTS and record travel and activity information into travel diaries in the travel packages sent to them when they agreed to participate. Multilanguage packages are available.

A pilot is desired to evaluate and assess the methods, survey design, materials, GPS methods, and process of survey activities to make the HTS reliable. Travel data collection is through a travel-activity diary. After the assigned survey day, retrieval calls are made with the purpose of collecting the trip and activity information. All the individuals in the sample household are supposed to report their trip information. If for some reason some members in the household cannot complete the diary, a proxy is allowed to report the information. Then, the overall travel diaries are returned by mail. Finally, vendors code the data information with the format specified by TxDOT to a data server for further travel data analyses.

Recruitment

TxDOT has specified how the sample households are generated and what the size of sample households should be. The sample households are supposed to be randomly selected. The typical approaches to recruit households to participate in an HTS are phone-number-based random

selection and mail-address-based random selection. TxDOT adopts phone-number-based sample selections instead of mail-address-based samples. TxDOT requires the vendor to develop or acquire a telephone number list containing the residents living in the survey area. The listed and unlisted phone numbers should have the same nonzero probability of selection. A script is prepared to solicit the sample household when the vendor contacts households.

Several researchers have found that a web survey is a good way to explain how important the HTS is and can be used to briefly introduce the basic process of the HTS. This method can improve the rate of participation. The web survey can convince some potential households to participate in the HTS. TxDOT does not specify this method in the specification.

The vendor is required to keep recruitment call logs including all responses and nonresponses. This documentation of call logs should include:

- Number of households attempted to contact
- Number of households contacted
- Contacted telephone numbers
- Date of contacts
- Time of calls using military time format
- Identification of each call's resolution

For any question or comment regarding the HTS, a toll-free 1-800 telephone number is established prior to the HTS. TxDOT requires the vendor to keep the entire call log of recruitment Monday to Friday from 7:00 a.m. to 9:00 p.m., and the weekend log uses a prerecorded message approved by TxDOT. The call logs include:

- Date of the call
- Time of calls using military time format
- Specific details of the nature or purpose of the calls
- Survey location

Pilot Survey for HTS

A pilot survey for an HTS is desired to evaluate the process of the HTS. Current practice in HTSs in Texas is to ask the vendor to conduct a pilot survey. The vendor is required to assess and evaluate the methods, materials, instrument, sample selection, data retrieval, and geocoding with activity travel diaries. The pilot is designed to:

- Emulate the whole process of a practical HTS including sample generation, telephone recruitment, survey mail-out, reminder call, retrieval call, data entry, trip geocoding, and edit check
- Conduct a subsample using GPS technology with a rational amount

The main items that should be assessed are:

- Response rate of household to participate via telephone recruitment
- Proportion of recruited households submitting complete travel data
- Adequacy of survey forms and scripts for recruitment and retrieval
- GPS evaluation on the function, software, and data collected
- Use of edit check programs to test data input and file structure for errors

In addition to pilot surveys, a pretest is possibly needed depending on the restrictions of budget and time of the HTS plan.

Mail-Out Notification and Reminder

A pre-notification letter should be mailed to all households randomly selected to participate in the survey, and all the calls and documents from the vendor must be bilingual in English and Spanish. The vendor should prepare and provide:

- An activity survey packet that contains a general information pamphlet explaining the survey and activity travel diary for each member in a household
- English and Spanish versions of the survey instruments for use
- Thank you letters and travel day reminder sheets
- Postage-paid return envelopes
- Contact names and a toll-free 1-800 number

Reminder calls are made to each household on the day before the assigned travel day. The vendor needs to do:

- Confirm that the participating households have received the survey packets
- Request that specific address or nearest intersecting streets be recorded in the surveys
- Answer questions regarding the survey
- Schedule a call-back time for the data retrieval call

Data

Survey data is mainly divided into three categories: household information, household vehicle information, and travel/activity information. The travel days should be Monday to Friday on non-school holidays during the local area school year and usually are 24 hours. Table 4 shows the data needed by TxDOT specification.

Table 4. TxDOT Data Needed.

Household Information	Number of persons in the household; annual household income and type of residence; person information: age, gender, ethnicity, employment, student status, occupation by employment category; employment information: self-employed, employer name and address, home office or business, telecommuting.
Vehicle Information	Number owned, number available, make, model, commercial or private use.
Travel/Activity Information	Name and address of activity, type of activity, purpose and mode of travel for each trip, type of vehicle used, number of persons in vehicle and if passenger or driver, vehicle used by non-household members, bus and parking information, start and arrival times for each trip.

Data Retrieval

On the prescheduled day, the vendor should call back to collect data. A minimum of 90 percent completeness of the activity travel diary is needed. According to specifications:

- Additional time for data retrieval is allowed for households to complete and return the diary by mail or Internet
- If the household is not contacted or the household asks for additional time, then data retrieval should begin no later than four days after the assigned travel day and fully completed within seven days of the household's travel date

- If no contact has been made with the household within four days, the household should be replaced
- Each member in the same household should be interviewed and a proxy is allowed. After the activity information and household information is obtained by phone, the household should mail back the activity travel diary in a prepaid envelope. The vendor should code the interview information and check to determine if any information is missing or unclear
- If the household reported no trips on the travel day, a supervisor should review and validate if the response is reasonable and then send the no-geocoded data for zero-trip households to the designated TxDOT representative to specify which data is valid and which data is replaced within 48 hours of the data's retrieval. If the response is not reasonable, the household is considered a non-respondent and should be replaced

GPS Data Collection

GPS is used for passive data collection from a subsample of participating households in an activity travel survey. The vendor is required to:

- Provide a survey implementation plan including GPS equipment with set-up and operation details, GPS power source, and GPS data elements
- Install and remove GPS and data recording equipment on up to three available vehicles per household
- Attempt to retrieve completed and useable data

Data Process

The vendor is required to use edit check programs to check the survey data to identify the records with errors, missing or incomplete information, and illogical data response. All these data is specified by TxDOT data file formats. All the data referring to spatial information should be geocoded to longitude, latitude, and traffic analysis zone system.

Since TxDOT survey practice is fairly standardized, Table 5 summarizes and compares the findings from the recent travel surveys in Lubbock, Waco, and JOHRTS.

Table 5. Travel Survey Findings from Lubbock, Waco, and JOHRTS.

Lubbock 2006–2007	Waco 2007–2008	JOHRTS 2008–2009
97% of the households had a vehicle	92% of the household had a vehicle	96% of the household had a vehicle
98% of the household had a licensed driver	95% of the household had a licensed driver available	96% of the household had a licensed driver
Trip rates per household increased with household size, with household income, and with vehicle available	Trip rates per household increased with household size, with household income, and with vehicle available	Trip rates per household increased with household size, with household income, and with vehicle available
The average vehicle occupancy was 1.44 persons per vehicle	The average vehicle occupancy was 1.5 persons per vehicle	The average vehicle occupancy was 1.5 persons per vehicle.
Over 95% of all person trips were made in a personal-use vehicle	Over 95% of all person trips were made in a personal-use vehicle	Over 96% of all person trips were made in a personal-use vehicle
67% drove a vehicle, 29% rode as a passenger, less than 2% walked, less than 1% used public transportation	64% drove a vehicle, 32% rode as a passenger, 2% walked, less than 1% used public transportation	71% drove a vehicle, 24% rode as a passenger, 1% walked, less than 1% used public transportation
Less than 16% did not make an internal trip on the survey day	Just over 25% did not make an internal trip on the survey day	Just over 24% did not make an internal trip on the survey day
Each person made 3.8 person trips per day, and each household made 9.7 person trips per day	Each person made 3.2 person trips per day, and each household made 8.5 person trips per day	Each person made 3.6 person trips per day, and each household made 9.1 person trips per day
	The average person trip length was 5.8 miles, and the average person trip duration was 8.8 minutes	The average person trip length was 6.5 miles, and the average person trip duration was 10.3 minutes
	The average vehicle trip length was 6.3 miles, and the average vehicle trip duration was 9.4 minutes	The average vehicle trip length was 6.7 miles, and the average vehicle trip duration was 10.5 minutes
The peak hour for household travel was from 7:01 a.m. to 8:00 a.m., during which 11% of the trip starts occurred. The second highest hour for household trip starts was from 5:01 p.m. to 6:00 p.m. when 10% of the daily trip starts occurred	The peak hour for household travel was from 7:01 a.m. to 8:00 a.m., during which 13% of the trip starts occurred. The second highest hour for household trip starts was from 3:01 p.m. to 4:00 p.m. when 11% of the daily trip starts occurred	The peak hour for household travel was from 7:01 a.m. to 8:00 a.m., during which 12% of the trip starts occurred. The second highest hour for household trip starts was from 3:01 p.m. to 4:00 p.m. when 11% of the daily trip starts occurred
	Weekly school year household travel internal to the study area scouted for an estimated 4.49 million vehicle miles of travel	Weekly school year household travel internal to the study area scouted for an estimated 6.1 million vehicle miles of travel

LEVEL OF STANDARDIZATION OF TXDOT HTS

TxDOT has detailed specifications of HTS practices. The following sections summarize the level of standardization with regard to the recommended practice.

From the document of household travel survey standard, TxDOT specified:

- The type of travel survey
- Household recruitment
- Support provided
- Bilingual service
- Data retrieval method
- Data retrieval process
- Pilot survey
- Passive data collection via GPS technology
- Data process in editing and geocoding

The fields that TxDOT unspecified include:

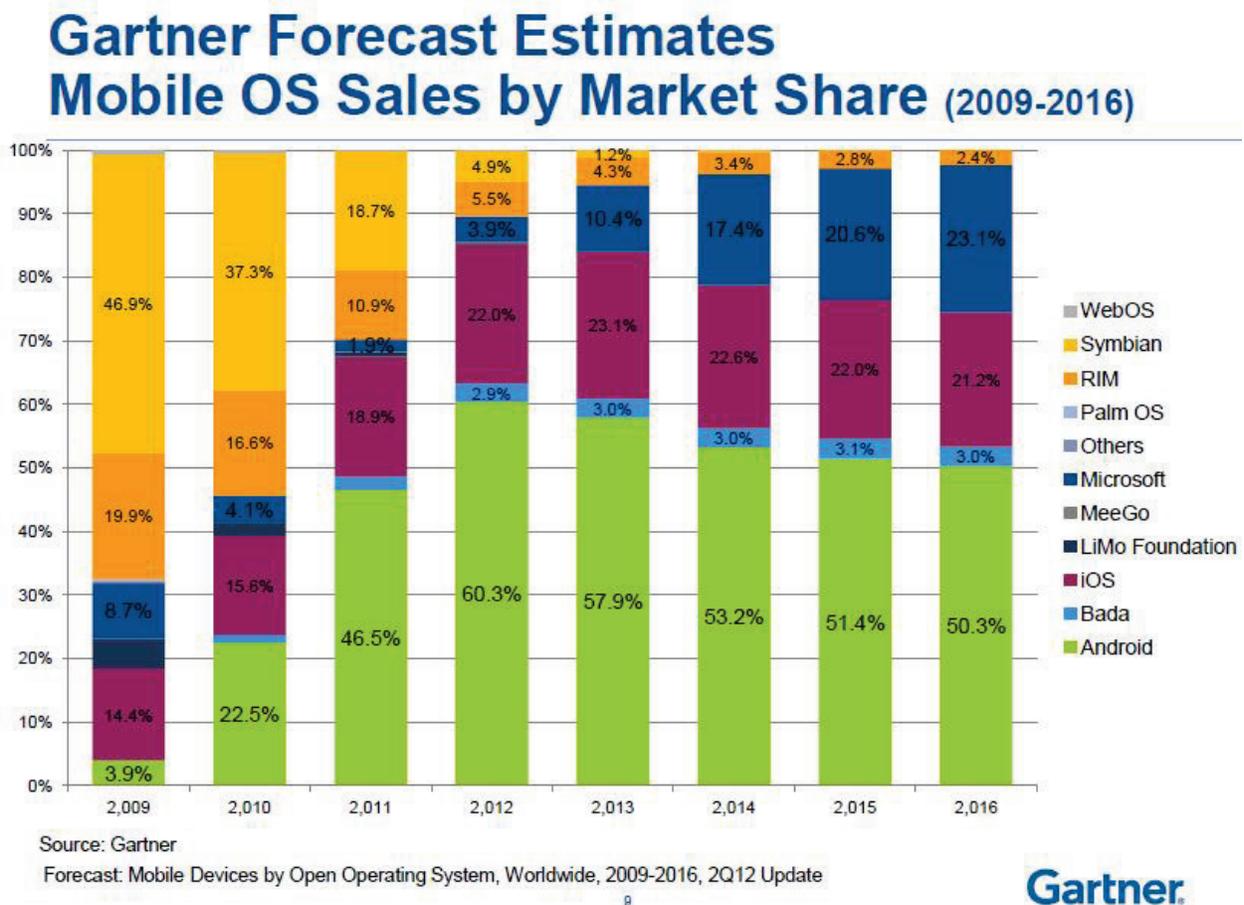
- Web survey
- HTS pre-test
- Subsample size of pilot survey

EVALUATING EXISTING APPLICATIONS

INTRODUCTION

A project from the Pew Research Center shows that nearly half of American adults owned a smartphone in 2012 (39). Due to the popularity of smartphones, using GPS-embedded smartphones can be an alternative method to perform an HTS. Figure 2 shows statistics from Gartner about an estimation of mobile operating system (OS) sales by market shares in 2009–2016 (40). It shows that Android and iOS are the leading mobile OSs in the market since 2009.

Figure 2. Gartner Forecast Estimates of Smartphone Devices by OSs.



In 2012, Gartner collected data and showed that Android and iOS are the leading mobile devices in sales, and the Android OS device has the most mobile market share. Table 6 lists the statistics of mobile device sales by OS in 2012 from Gartner (41).

Table 6. Worldwide Mobile Device Sales (Thousands of Units) by OS in 2012 (41).

Operating System	2012 Units	2012 Market Share (%)	2011 Units	2011 Market Share (%)
Android	98,529.3	64.1	46,775.9	43.4
iOS	28,935.0	18.8	19,628.8	18.2
Symbian	9,071.5	5.9	23,853.2	22.1
Research In Motion	7,991.2	5.2	12,652.3	11.7
Bada	4,208.8	2.7	2,055.8	1.9
Microsoft	4,087.0	2.7	1,723.8	1.6
Others	863.3	0.6	1,050.6	1.0
Total	153,686.1	100.0	107,740.4	100.0

Compared with the GPS method to collect trip data, the smartphone-based method has the advantages of lower cost and burden on both surveyors and participants. There have been several research studies using an application on smartphones to perform an HTS. Additionally, in the app stores, a few applications have already been published and used for travel surveys.

EXISTING APPLICATIONS RUNNING ON IOS

This section reviews eight applications with regard to tracking routes for iPhones and examines two applications that could be used for a travel survey. Researchers tested the functions, features, and operations.

CycleTracks

CycleTracks (Figure 3) was developed under the San Francisco County Transportation Authority to support users by tracking their bicycle trip routes.

The app is triggered by a start button. It records the ride and saves the data at the end with a specification of trip purpose. A user can also cancel the recording after it starts. Each record is saved into the smartphone and uploaded to a server.

The app has four tab bars at the bottom. The instruction section contains some basic information and usage explanations. The record feature is used to trigger, save, and cancel a recording. The elapsed time, estimated distance, estimated speed, and tracking map all display on the screen.

The “My Trips” section is where each trip record is saved. The settings feature is used for setting personal information including age, mailing address, gender, zip codes, and cycling frequency.

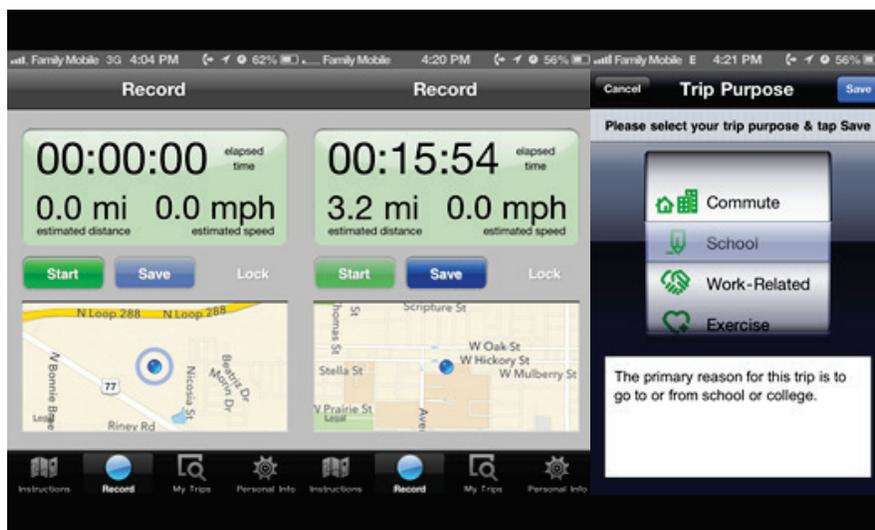
Figure 3. CycleTracks Screenshot.



PaceLogger

PaceLogger (Figure 4) was developed by NuStats and was used in complex and large-scale social research studies and data analytics. The functions, features, and screen display are the same as with CycleTracks.

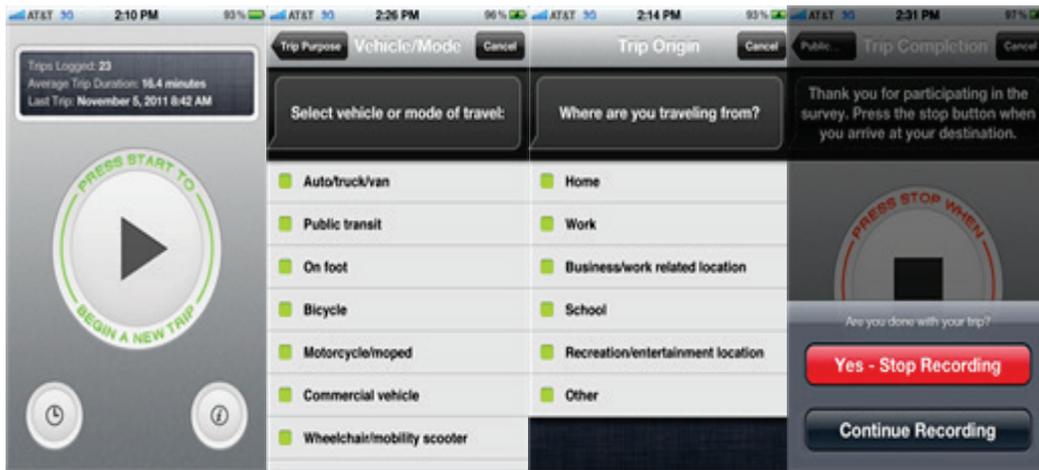
Figure 4. PaceLogger Screenshots.



RouteScout

RouteScout (Figure 5) was developed by NuStats to support real-time GPS logging and activity logging for travel surveys. It can run on both iOS and Android. It is triggered by a green button on the screen to record a trip. Household information can be saved in the demographics section. Setting information is located under a special options section. The history section shows previous trips.

Figure 5. RouteScout Screenshots.



BATTERY LIFE, DATA STORAGE, AND TRANSFER

Researchers carried an iPhone 5 to empirically test the battery drain when an application was running on the device and then, based on the real usage of the battery, generated curves to show how the battery drained when in use. This section describes the results. Table 7 is the device specification.

Table 7 Device Specification

Device Detail	
Model	iPhone 5
System Version	6.1.4
Capacity	64G
CPU	Apple A6 (Dual Core)
Frequency	1.3GHZ
Battery Voltage	3.8V
Battery Capacity	1424mAh

Test Description

Researchers tested two applications, PaceLogger and CycleTracks, which can run in the background when the tester is taking a school shuttle bus. During the test, researchers turned off all the other applications except the application being tested in order to keep the battery at the lowest usage. As for the location setting, researchers turned GPS off for all other applications except PaceLogger and CycleTracks. The battery was fully charged before starting the test. After triggering an application, researchers immediately turned off the screen. Researchers took a screenshot every 10 minutes within the 30 testing minutes and saved the screenshots in the photos section of the device.

During the test, several text messages were received and sent intentionally. For experimental records, researchers took a screenshot for each step of the test. These are all the operations made on the device in the test.

Battery Drain Curve

The data uploading may not consume much power because the uploading is controlled by the user after finishing a survey rather than by real-time uploading. Researchers first tested PaceLogger starting with full power and then tested CycleTracks.

Figure 6. PaceLogger Battery Life.

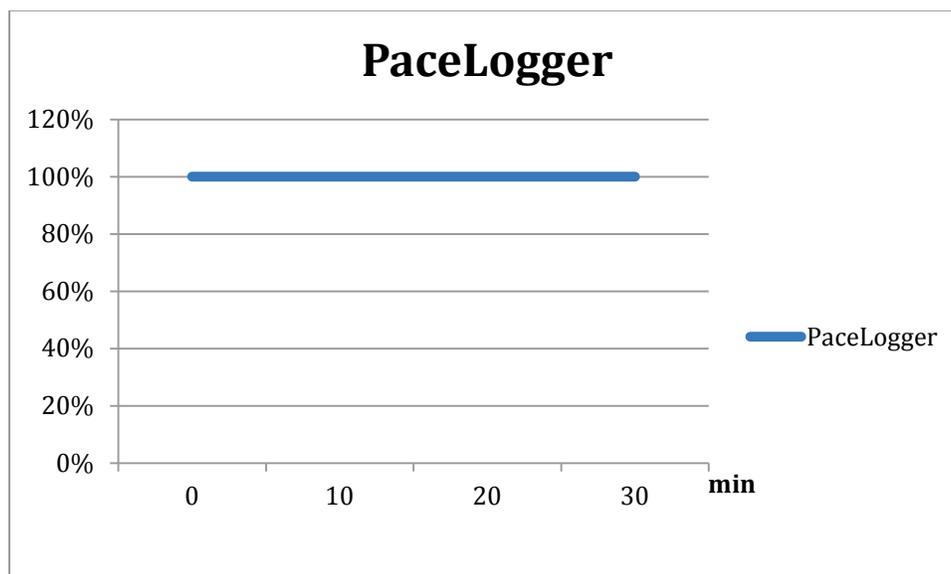


Figure 7. CycleTracks Battery Life.

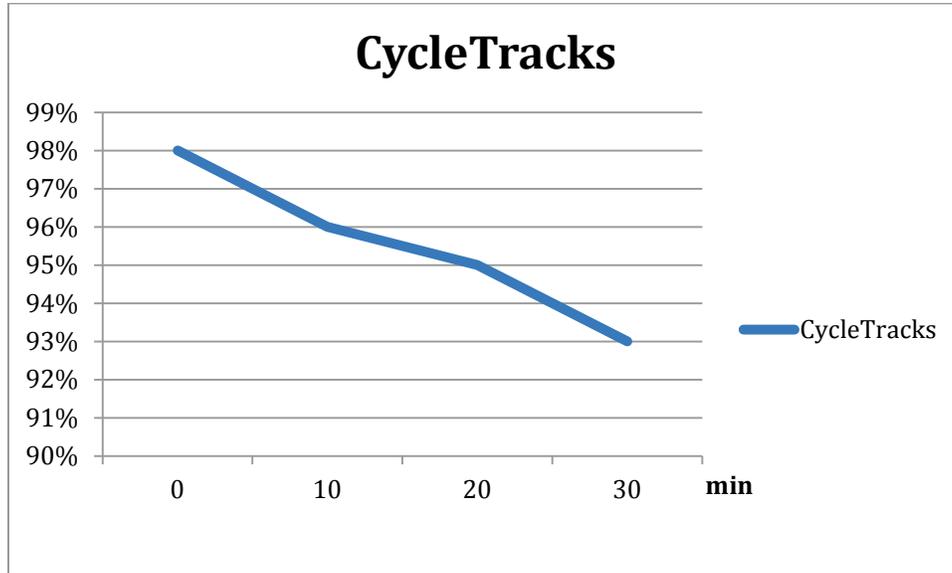


Figure 6 shows that within the 30-minute test duration, PaceLogger did not drain much power, and at the end of the test, the battery power was still at 100 percent. In contrast, Figure 7 shows that the CycleTracks battery test started at 98 percent and drained down to 93 percent after the trips. CycleTracks consumed around 5 percent power within 30 minutes. Researchers suggest that this app is still satisfactory for a household travel survey if the travel activities will not last a long time.

Data Storage and Transfer

When a survey was finished, the data was automatically saved on the local device and uploaded to a server at the same time. The data estimation capacity of 30 minutes from the test was 295,234 bytes. In an HTS, if the travel days assigned are one or two days, the device storage is satisfactory for the data capacity.

Data Matching

Next, researchers compared the data items collected from the application with the data items required by TxDOT and found that some of the items could be detected by applications but some

could not be derived. Table 8 lists the PaceLogger matching data items from TxDOT and the tested applications. Table 9 is the list of CycleTracks data items.

Table 8. Matching Data Items—PaceLogger (iOS Version).

	TxDOT Data Requirement	Application Data Collection (PaceLogger)
Household Information	Number of persons in the household, annual household income and type of residence, age, gender, ethnicity, employment, student status, occupation by employment category, self-employed, employer name and address, home office or business, telecommuting	Age, gender.
Vehicle Information	Number owned, number available, make, model, commercial or private use	None.
Travel/Activity Information	Name and address of activity, travel date, type of activity, purpose and mode of travel for each trip, type of vehicle used, number of persons in vehicle and if passenger or driver, vehicle used by non-household members, bus and parking information, start and arrival times for each trip	Home address, work and school zip, travel purpose, travel date, start and arrival times for each trip. Origin and destination will be shown on the map.

Table 9. Matching Data Items—CycleTracks (iOS Version).

	TxDOT Data Requirement	Application Data Collection (CycleTracks)
Household Information	Number of persons in the household, annual household income and type of residence, age, gender, ethnicity, employment, student status, occupation by employment category, self-employed, employer name and address, home office or business, telecommuting.	Age, gender.
Vehicle Information	Number owned, number available, make, model, commercial or private use.	None.
Travel/Activity Information	Name and address of activity, travel date, type of activity, purpose and mode of travel for each trip, type of vehicle used, number of persons in vehicle and if passenger or driver, vehicle used by non-household members, bus and parking information, start and arrival times for each trip.	Home address, work and school zip, travel purpose, travel date, start and arrival times for each trip. Origin and destination will be shown on the map.

Conclusion

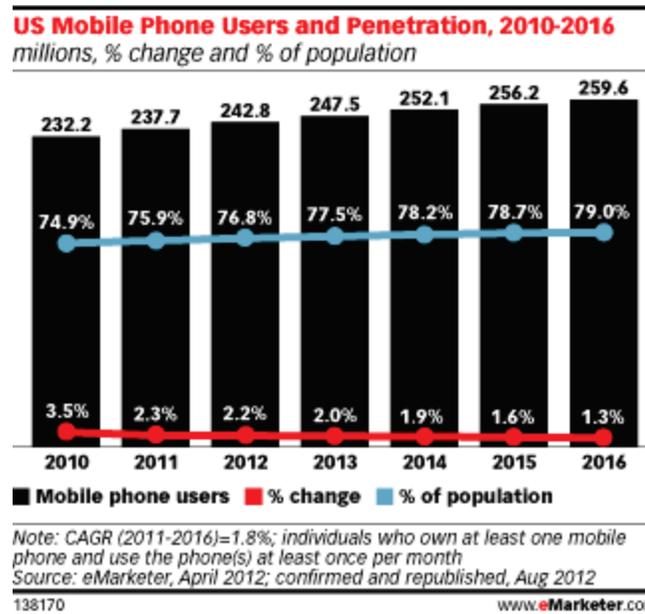
In this task, researchers mainly tested and evaluated two applications, PaceLogger and CycleTracks, on how they work and what their functions and features are. For device limitations,

researchers paid more attention to the battery life and storage capacity when the application is running and found that under low smartphone usage, the battery drained no more than approximately 5 percent power in 30 minutes if the battery was fully charged. In a 30-minute test, the trip data occupied around 295,234 bytes, which was well under the smallest device storage limitation of 16G. However, based on matching data items, most of the required data items could not be detected by existing applications. For supporting a household travel survey, more functions and data item collections should be developed.

EXISTING APPLICATION RUNNING ON ANDROID

There has been a drastic increase in the use of smartphones due to the various options such as route tracking, video chat, music players, cameras, and many other features that come on the devices. According to eMarketer (42), smartphone users in the U.S. in 2016 will comprise 58.5 percent of the population (Figure 8). Figure 9 shows the U.S. mobile phone users and penetration from 2010–2016 according to eMarketer (42).

Figure 8. Mobile Phone Graph from eMarketer.



Smartphones can be very helpful in travel surveys, as they can determine the location and speed of a trip and collect information from a large number of users at a time about various trips and trip locations. A few Android mobile applications were developed in the past for similar

purposes, namely AggieTrack, CycleTracks, FM Survey, and GPS-ATD. AggieTracks and CycleTracks applications were tested using an Android smartphone. Table 10 is the device specification. Battery usage was checked by using the built-in option provided in the phone settings.

Table 10 Android Device Specification

Phone Make	Samsung Galaxy Exhilarate™
Model	SAMSUNG-SGH-I577
System Version	Android 2.3, Gingerbread
Started Usage	July 29, 2012
Battery Features	1759mAh in battery size; Up to 10.4 days standby time; Up to 7 hours continuous usage;

AggieTrack

Background and Purpose

AggieTrack (Figure 9) was developed for Texas A&M University URSC 493 Transportation Research Project and is a travel survey. It collects the user details, modes of transportation, and trip purpose, which are uploaded to the server (Table 11). The app runs in the background.

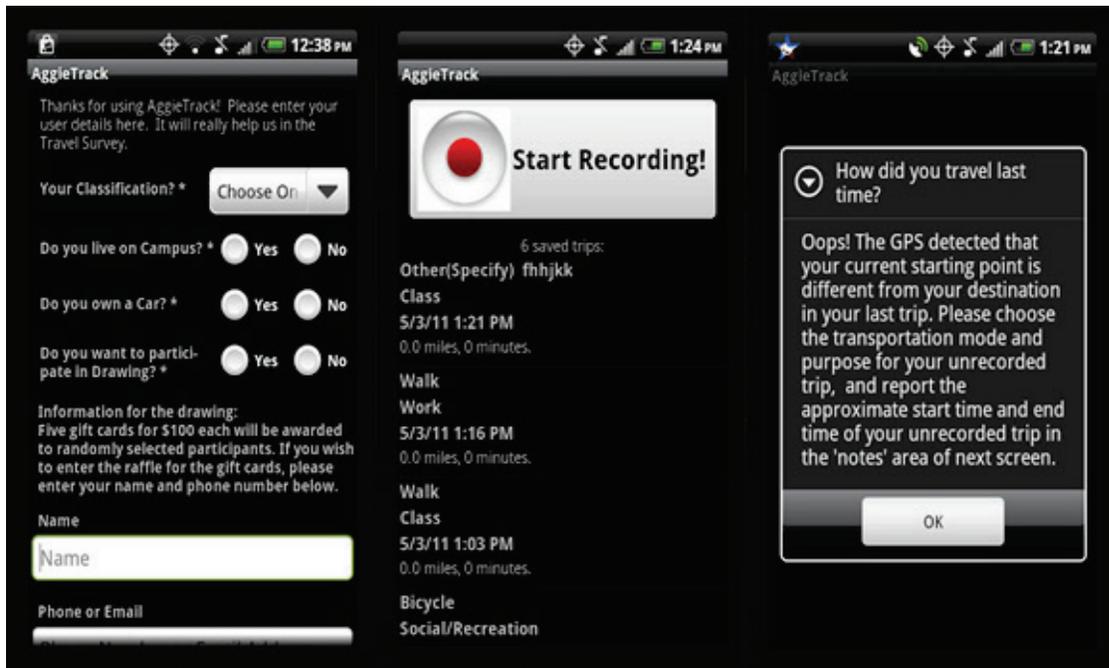
Functionalities

The functionalities of AggieTrack are listed as the following:

- The trip distance traveled, time lapsed, current speed, and average speed can be recorded.
- This application can be paused and locked.
- Modes of transportation and trip details are collected.
- Records of previous trips are displayed.

- The trip details will be uploaded after each trip.

Figure 9. Screenshots of the AggieTrack App (Android Version).



Data Storage

Data is uploaded to the server.

Battery Use

AggieTrack uses a battery equivalent to voice calls. Continuous usage of AggieTrack would drain the battery drastically. AggieTrack uses 9 percent of the battery.

Table 11. Matching Data Items—AggieTrack (Android Version).

	TxDOT Data Requirement	Application Data Collection (AggieTrack)
Household Information	Number of persons in the household, annual household income and type of residence, age, gender, ethnicity, employment, student status, occupation by employment category, self-employed, employer name and address, home office or business, telecommuting	On campus or not, name, phone number
Vehicle	Number owned, number available, make,	Car owned or not

Information	model, commercial or private use	
Travel/Activity Information	Name and address of activity, travel date, type of activity, purpose and mode of travel for each trip, type of vehicle used, number of persons in vehicle and if passenger or driver, vehicle used by non-household members, bus and parking information, start and arrival times for each trip	Notes about trip, purpose and mode of travel, start date and time, total trip time, missed trip details, distance, speed, trip route

CycleTracks

Background and Purpose

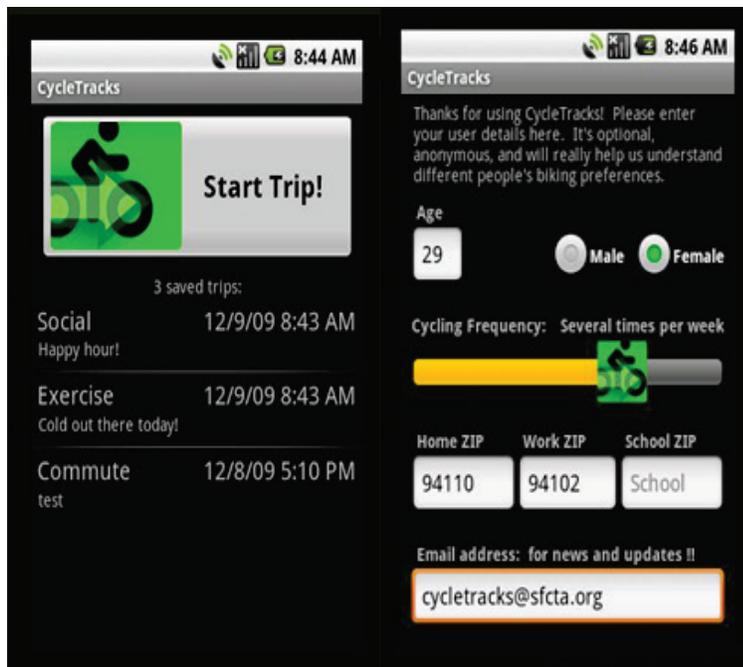
Data on bicycle routes were preferred by local cyclists in the San Francisco County area. Thus, SFCTA developed a smartphone app named CycleTracks (Figure 10). This trip-tracking app was developed for data collection in the San Francisco region for models that would predict route types cyclists were likely to utilize based on characteristics of riders and bike networks. The app can be downloaded to iPhone and Android smartphones. This app runs in the background.

Functionalities

The functionalities of CycleTracks are listed as the followings.

- Download and installation is quick.
- The app requires a minimum number of taps/clicks to operate.
- Uses smartphone GPS provision to record consumers' bicycle trip routes and times and display their ride maps.
- Users can enter personal information.
- Bicycle bell sounds and vibration occurs after initial 15 minutes to signify GPS data collection.
- End of each trip, trip purpose, route, date, and time are sent to SFCTA.

Figure 10. Screenshots of the CycleTracks App (Android Version).



Data Storage

CycleTracks is capable of storing GPS data on the device and transferring it to a server once a network connection is built (Table 12). Trip data can be corrected using map-matching algorithms and smoothing techniques if the trip data suffers from urban canyon effect where the GPS signal is weak.

Battery Use

Battery-saving features are programmed into the app. A few of these are dimming of the screen's backlight all through operation and auto turn off when charge falls below 10 percent. CycleTracks uses 3 percent of the battery.

Data Management and User Incentives

For bicycle coalitions in the CycleTracks study, bike lock stickers were distributed to the participants, and to encourage more people to participate in the survey, users who included an email address and uploaded a minimum of one trip were entered into a drawing for a \$50 iTunes gift card. Trips are uploaded and saved to a consumer's personalized trip list, and trip traces can be viewed in Google Maps format.

Table 12. Matching Data Items—CycleTracks (Android Version).

TxDOT Data Requirement		Application Data Collection (CycleTracks)
Household Information	Number of persons in the household, annual household income and type of residence, age, gender, ethnicity, employment, student status, occupation by employment category, self-employed, employer name and address, home office or business, telecommuting	Home zip, age, gender, email address
Vehicle Information	Number owned, number available, make, model, commercial or private use	
Travel/Activity Information	Name and address of activity, travel date, type of activity, purpose and mode of travel for each trip, type of vehicle used, number of persons in vehicle and if passenger or driver, vehicle used by non-household members, bus and parking information, start and arrival times for each trip	Work, school zip, notes about trip, purpose and mode of travel, start date and time, total trip time, distance Speed, cycling frequency, trip route

Future Mobility Survey

Background and Purpose

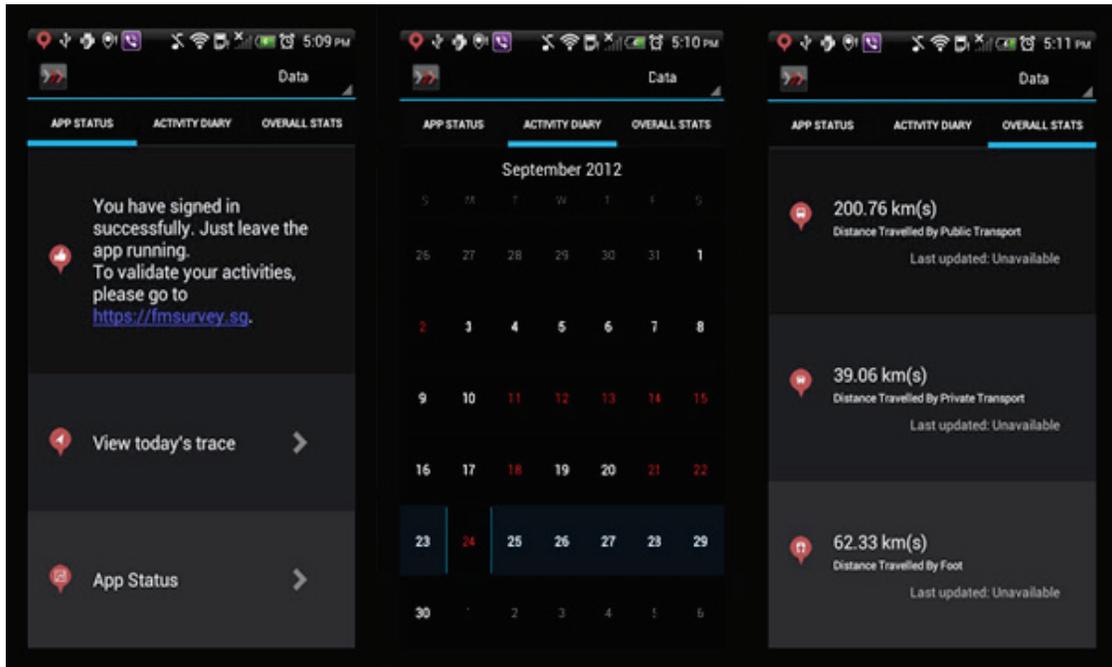
The Future Mobility Survey (Figure 11) is a Singapore-based transport survey developed by the Singapore–MIT Alliance for Research and Technology. The survey can enhance the effectiveness of traditional household travel surveys through a combination of standard questions and web-based prompted-recall surveys. It makes smartphone usage for location tracking significant.

Functionalities

The functionalities are described as the following:

- Tracks location and validation of identified stops and activities and combines them with transport modeling activities.
- Part of a household travel survey.
- Gets precise location using GPS.
- Survey collects data about where families go and how they get there.
- All collected information is kept confidential.

Figure 11. Screenshots of the Future Mobility Survey App (Android Version).



Data Collection

The Future Mobility Survey will collect data in the fields of:

- General individual and household demographic overview
- Questions that evaluate individual attitudes about transportation and housing options
- Users are asked to report more thorough information about recorded activities (Table 13)

Battery Use

To reduce battery usage, restrictions are placed on smartphone data transmissions to the server. Location transmission happens only after sufficient new data collection. FM Survey was developed to determine sufficient balance between battery conservation and precision.

Incentive

In the original FM Survey study, an incentive of SG\$30 was planned for each of the 100–125 participants.

Table 13. Matching Data Items - Future Mobility Survey.

TxDOT Data Requirement		Application Data Collection (FM Survey)
Household Information	Number of persons in the household, annual household income and type of residence, age, gender, ethnicity, employment, student status, occupation by employment category, self-employed, employer name and address, home office or business, telecommuting	
Vehicle Information	Number owned, number available, make, model, commercial or private use	
Travel/Activity Information	Name and address of activity, travel date, type of activity, purpose and mode of travel for each trip, type of vehicle used, number of persons in vehicle and if passenger or driver, vehicle used by non-household members, bus and parking information, start and arrival times for each trip	Public or private, transportation, travel diary, distance

GPS-ATD

Background and Purpose

The GPS-ATD project (Figure 12) was completed in 2009 by AHMCT. The project was tested on the HTC Magic phone, which runs on the Android operating system. GPS-ATD reduces user burden all through household travel surveys. It provides accurate, reliable, and spatially dense travel behavior information (Table 14).

Functionalities

The functionalities are listed as the following:

- User can start the app when the trip starts.
- User can select various modes of travel.
- Used for household travel surveys.

Figure 12. Screenshots of the GPS Automated Travel Diary App (Android Version).

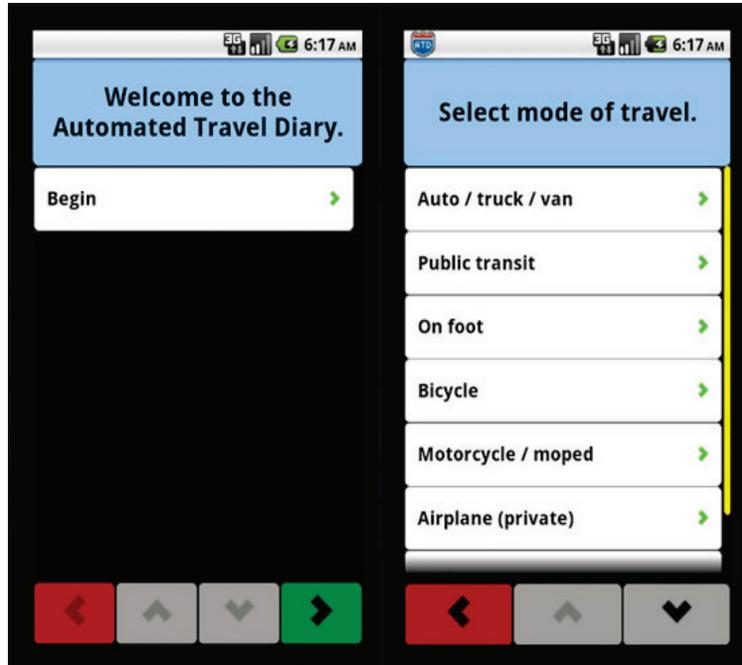


Table 14. Matching Data Items—GPS-ATD App.

TxDOT Data Requirement		Application Data Collection (GPS-ATD)
Household Information	Number of persons in the household, annual household income and type of residence, age, gender, ethnicity, employment, student status, occupation by employment category, self-employed, employer name and address, home office or business, telecommuting	Full name, email address
Vehicle Information	Number owned, number available, make, model, commercial or private	
Travel/Activity Information	Name and address of activity, travel date, type of activity, purpose and mode of travel for each trip, type of vehicle used, number of persons in vehicle and if passenger or driver, vehicle used by non-household members, bus and parking information, start and arrival times for each trip	Modes of travel , vehicle position, speed

CONCLUSION

Most of the applications mentioned above have been used for HTSs. Various techniques have been used in different apps for reduction in battery consumption.

Though there are a number of apps that can perform surveys (Table 15), every app has its own features, and a few of these features need to be added and a few need to be ignored for the

TxDOT project. An inclusion of unnecessary features would consume more battery and would make the interface complicated.

Table 15. Comparison of Smartphone Apps.

Application	Developer	Website	System	Battery Usage	Functions
AggieTrack	Texas A&M University and Bryan-College Station	https://play.google.com/store/apps/details?id=edu.tamu.aggietrack&hl=en	iOS and Android	More	1) Modes of transportation and trip details are collected 2) Records of previous trips are displayed 3) Uploads the trip details after each trip
CycleTracks	San Francisco County Transportation Authority	http://www.sfcta.org/mode/ling-and-travel-forecasting/cycletracks-iphone-and-android	iOS and Android	More	1) Record bicycle trip routes and time. 2) Data is sent to SFCTA after trips 3) Ride map display 4) Collect trip purpose, route, time
FM Survey	Singapore–MIT Alliance for Research and Technology	https://play.google.com/store/apps/details?id=edu.mit.smart.fmsurvey.android&feature=search_result#?t=W251bGwsMSwyLDEsImVkdS5taXQuc21hcnQuZm1zdXJ2ZXkuYW5kcm9pZCJd	iOS and Android	Less	1) Record start time, end time and total time of a trip 2) Retrieve trace 3) List the modes of travel with distance for each trip
GPS-ATD Survey	AHMCT	https://play.google.com/store/apps/details?id=edu.ucdavis.ahmct.atd.android.atd.Android&hl=en	Android	Less	1) Record GPS data, speed 2) Collect travel modes

CLASSIFICATION OF DATA ELEMENTS IN TXDOT TRAVEL SURVEY

INTRODUCTION

The currently available travel survey applications cannot completely support the TxDOT household travel survey. From the prior tasks, the existing applications only support a little portion of the required data elements of TxDOT. Thus, the researchers in this task attempt to explore a new method to perform smartphone-based HTS for TxDOT and evaluate whether the new method is satisfactory for an HTS in Texas.

This section first works on the classification of the entire data elements based on the requirement of TxDOT. The second section then endeavors to develop an iOS app, TravelSurvey that can completely support an HTS in Texas and describes how the app was developed. The last section is to evaluate TravelSurvey to decide whether it is a full-function app in a HTS by a pilot HTS and a semi-structured interview.

HOUSEHOLD TRAVEL SURVEY DATA CLASSIFICATION

The data elements listed in the TxDOT data file format are divided into four categories: household (HH) information, person information, vehicle information, and trip information. These data elements are classified into two modes of data collection: interactive and passive. The interactive data elements are collected from users' input, and the passive data is detected by the device without any input from users. The sample number identifies participants, and it is automatically assigned by the system.

Table 16, Table 17, Table 18, and Table 19 are all the interactive data classification, which derives from "TXDOT DATA FILE FORMATS."

Table 16. Interactive Data Elements—Household Information.

Data Category	Data Requirement	Data Collection From
Household Information	Record Type	Database
	Sample Number	Automatically assigned
	Phone Number	1
	Month	Detected by System
	Day	Detected by System
	Day of Week	Detected by System
	Advanced Letter	2
	Address	Detected by System
	City	Detected by System
	Zip Code	Detected by System
	HH Country	Detected by System
	HH Study Area	Detected by System
	HH Zone	Detected by System
	Longitude	Detected by System
	Latitude	3
	Number Persons	4
	Number Employed	5
	Vehicles Available	6
	Vehicles Owned/Leased	7
	Bikes	8
	Residence	9
	Other Residence	10
	Tenure	11
	Previous Residence	11
	Previous Zip Code	12
	HH Factors	13
	Other Factors	14
	Income	14
	Sample HH Income	15
	Day Visitors	16
	Overnight Visitors	17
	Delivery Vehicle	18
	Number Delivery Driver	19
Phone Service	20	
Time Without	21	
HH Vehicle Use by None HH-Number	22	
Share Phone	23	
GPS House	Always True	
Total HH Trips	Database	

Household Information

The following is the list of questions that will be inquired during an HTS under the category of household information.

1. What is your phone number?
2. Do you receive an advance letter?
3. How many persons are living in the household?
4. How many persons who are living in the household are employed?
5. How many vehicles does your household own?
6. How many vehicles are Owned/Leased?
7. How many bikes does your household own?
8. What is your residence type?
9. If your resident type was not in the previous list, please type it here.
10. How many years have you been living at your current residence?
11. What is your previous residence address? If none, please indicate so.
12. Which of the factors below influenced your decisions to currently live here?
13. Please list any other factors that were not on the list in question 12.
14. What is your household income?
15. How many people visited your residence on the travel day?
16. How many overnight visitors were in your household during the travel day?
17. Is there someone at your residence driving a form of delivery vehicle?
18. How many persons in your household are delivery drivers as part of their work?
19. How many times has your household lacked phone service within the past 12 months?
20. What is the average length of time your household has been without phone service?
21. Is there one or more household vehicles that were used by a non-household member on the travel day?
22. How many households share a phone line with yours?
23. How many household members used smartphone on the travel day?

Table 17. Interactive Data Elements—Person Information.

Data Category	Data Requirement	Data Collection From
Person Information	Record Type	Database
	Sample Number	Automatically assigned
	Person Number	1
	Relationship	2
	Head of Household	1
	Gender	3
	Ethnicity	4
	Ethnicity Other	5
	Age	6
	Licensed Driver	7
	Employment	8
	Employment Status	9
	Hours	10
	Not Employed	11
	Not Employed Other	12
	Delivery	13
	Transporting Cargo	14
	Commercial Service	Data from Vehicle Information
	Flex Time	15
	Job	16
	Employer Name	17
	Work Place Type	18
	Other Work Place	19
	Home Office	20
	Telecommute	21
	Workplace Address	22
	Workplace City	22
	Workplace Country	22
	Zip Code	22
	Work Study Area	22
	Work Zone	22
	Longitude	22
	Latitude	22
	Days Worked	23
	Work at Home	24
	Second Job Type	25
	Second Job Other	26
	Second Job Employment Status	27
	Total Hours	28
	Primary Occupation	29
	Primary Industry	30
	Secondary Occupation	31
	Secondary Industry	32
Student Status	33	
School Type	34	
School Type Other	35	
Hours Enrolled	36	
Bike Use	37	
Bike Purpose	38	
Disability	39	
Travel	40/Database	
Person Trips	Database	
Why No Travel	41	
Diary Use	42	
Proxy ID	43	
Date Data Was Retrieved	Database	

Person Information

The following is the list of questions that will be inquired during an HTS under the category of personal information.

1. What is your assigned person number?
2. What is your relationship to the head of household?
3. What is your gender?
4. What is your ethnicity?
5. If your ethnicity was not listed in question 4, please type it here.
6. What is your age?
7. Are you a licensed driver?
8. Are you an employed person with a paying or volunteer job?
9. What is your employment status?
10. How many hours do you work per day on average?
11. What is your reason for unemployment (if so)?
12. If your reason for unemployment was not listed in question 11, please type it here.
13. Are you a delivery driver?
14. Is the cargo being transported?
15. Does your employer allow you to work with flexible hours?
16. Do you have more than one paying job?
17. What is the name of your primary employer?
18. What is your workplace type?
19. If your workplace type was not listed in question 18, please type it here.
20. Is your workplace a home office?
21. If you are employed 30 or more hours per week, do you work from home by telecommute on a regular basis?
22. What is your workplace address?
23. How many days do you typically work per week?
24. In the last 7 days, how many days did you work at home instead of going to work?
25. What is your second job type?
26. If your second job type was not listed in question 25, please type it here.
27. What is your second job employment status?

28. How many total hours do you work per week?
29. What is your primary occupation?
30. What is your primary job industry?
31. What is your secondary occupation?
32. What is your secondary job industry?
33. Have you enrolled in any type of school?
34. What is your school type?
35. If your school type was not listed in question 34, please type it here.
36. Are you enrolled for 12 credit hours or more?
37. How many days did you ride a bike in the last 7 days?
38. What is your most common purpose for riding a bike?
39. Do you have a transportation disability?
40. Did you travel on the designated travel day?
41. If you didn't make trips on the travel day, why?
42. Did you use a diary to record trip information?
43. What is your proxy ID?

Table 18. Interactive Data Elements—Vehicle Information.

Data Category	Data Requirement	Data Collection From
Vehicle Information	Record Type	Database
	Sample Number	Automatically assigned
	Vehicle Number	1
	Type of Vehicle	2
	Other Vehicle Type	3
	Year	4
	Make	5
	Other Make	6
	Model	7
	Type of Fuel	8
	Other Fuel Type	9
	Commercial Use	10
	Odometer Reading	11
	Ownership	12
	Non-HH Vehicle Number	13
Non-HH Use	14	
Lighter	15	

Vehicle Information

The following is the list of questions that will be inquired during an HTS under the category of vehicle information.

1. What is your assigned vehicle number?
2. What is your vehicle type?
3. If your vehicle type was not listed in question 2, please type it here.
4. Please list the year of your vehicle.
5. Please list your vehicle's make.
6. If your vehicle's make was not listed in question 5, please type it here.
7. Please list your vehicle model.
8. What type of fuel do you use?
9. If your fuel type was not listed in question 8, please type it here.
10. Do you use your vehicles for commercial purposes?
11. What is your odometer reading at the beginning of the travel day?
12. What is the ownership status of your vehicle?
13. How many of your household vehicles are used by non-household members?
14. Was your vehicle used by a non-household member on the travel day?
15. Is your car's lighter (power outlet) working?

Table 19. Interactive Data Elements—Trip Information.

Data Category	Data Requirement	Data Collection From
Trip Information	Record Type	Database
	Sample Number	Automatically assigned
	Month	Detected by System
	Day	Detected by System
	Person Number	Detected from Person Information
	Activity/Trip Number	Database
	Activity Type Code	1
	Activity Description	2
	Location	3
	Location Address	3
	Location City	3
	Location Country	3
	Zip Code	3
	Exit Route Name	3
	Study Area	3
	Zone Number	3
	Longitude	3
	Latitude	3
	Type of Place	4
	Other Place	5
	Purpose	6
	Mode of Travel	7
	Other Mode	8
	Number of People	9
	HH Members	10
	Non-HH Members	Database
	Persons on Trip	11
	HH Vehicle	12
	Vehicle Used	13
	Body Type	14
	Other Body Type	15
	Other Vehicle Year	16
	Other Vehicle Make	17
	Other Vehicle Make Description	18
	Other Vehicle Model	19
	Other Vehicle Fuel	20
Other Fuel	21	
Other Vehicle Commercial Use	22	
To Bus Stop	23	
To Activity	24	
Off Bus Location	25	
Parking Location	26	
Parking Cost	27	
Payment Method	28	
Arrival Hour	Detected by System	
Arrival Minute	Detected by System	
Departure Hour	Detected by System	
Departure Minute	Detected by System	

Trip Information

The following is the list of questions that will be inquired during an HTS under the category of trip information.

1. What is your activity type?
2. Please briefly describe your trip activity.
3. What is your destination address?
4. What is the type of destination for the trip?
5. If the type of destination was not listed in question 4, please type it here.
6. What is the purpose for your trip?
7. What method of transportation did you use for your trip?
8. If the method of transportation was not listed in question 7, please type it here.
9. What is the number of people in the vehicle, including the driver?
10. How many household members were in the vehicle during the trip?
11. Which household members traveled with you? (Add commas between multiple members)
12. Is a household vehicle used to make this trip?
13. What is the vehicle number used for this trip?
14. What is your vehicle type for the trip?
15. If the vehicle type was not listed in question 14, please type it here.
16. What is the year for the vehicle used to make the trip?
17. What is the make for the vehicle used to make the trip?
18. If the vehicle make was not listed in question 17, please type it here.
19. What is the model for the vehicle used to make the trip?
20. What is the fuel type for the vehicle used to make this trip?
21. If your fuel type was not listed in question 20, please type it here.
22. Is the vehicle used to make the trip also used for commercial purposes?
23. Did you walk more than one block to the bus stop? Ignore this question if you do not take a bus.
24. Did you park or get off the bus more than one block away from your destination location? Ignore this question if you do not take a bus.
25. What is the address that you got off the bus? Ignore this question if you did not ride a bus.
26. What is the address that you parked your vehicle at? Ignore this question if you did not drive a vehicle to your destination.

27.How is your parking fee charged?

28.How much were you charged for parking?

TRAVELSURVEY APPLICATION

TravelSurvey is an iOS application for household travel survey data collection, and all the required data elements are completely collected from TravelSurvey without any outside assistance such as travel diary. The interactive data collection needs users to manually type the answers, and the passive data collection and spatial and temporal data, are automatically detected by the GPS and saved into a local device. The data will be uploaded to the server when the users click the “Submit” button. TravelSurvey is currently available at the App Store for free download. It is compatible with iOS 6 or higher on iPhone 4 or higher.

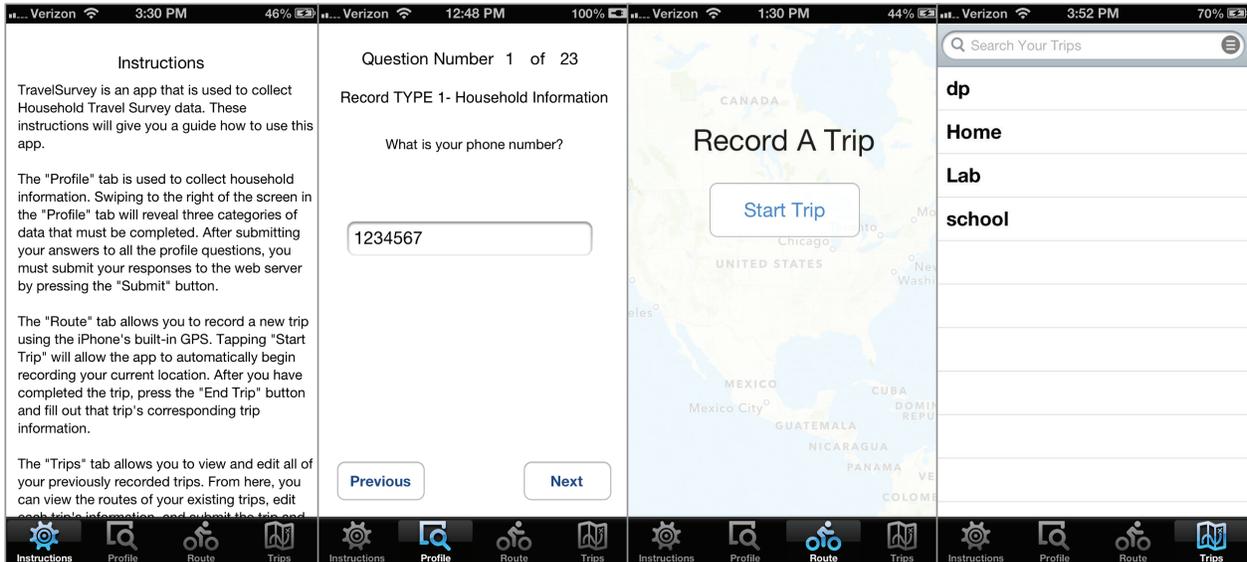
Function and Interface

To minimize the burden placed on participants and provide a concise experience on the app operations, the main interface of TravelSurvey has only four tab bars on the bottom of the screen, “Instructions,” “Profile,” “Route,” and “Trips.” From these tabs, the participants can view, edit and submit the data they have recorded. The whole of collected data from the app is based on the TxDOT’s HTS request process. Before loading the main interface of TravelSurvey, there are another two sub-views that will be loaded. The first sub-view is called Informed Consent Form (ICF) view that is required by the Institutional Review Board (IRB) of University of North Texas because the pilot survey uses humans in the research, and the survey questions contain privacy information. ICF asks the participants to consent to the pilot travel survey so that they can understand the purpose, procedures, and potential risks of the survey process. Thus, all the participants are supposed to be informed first. The second view, loaded after the ICF-view, is the registration view requiring participants’ personal contact information. The registration process is to assign them a unique sample number. The participants can only use the application if they agree to the consent form by clicking the button at the bottom and completing the basic online registration process.

The first tab on the main interface is named “Instructions.” The “Instructions” tab introduces the application’s functionality as well as how to use it. Additionally, it explains to a participant why TxDOT conducts a household travel survey, and why it adopts a smartphone method to collect data. By reading the instructions, participants are able to know how to record and upload data.

The instructions have been described in detail, so it is not necessary to assign the training as the GPS-based method provided before. Figure 13 is a screenshot of TravelSurvey in iOS 6.

Figure 13. Screenshot of TravelSurvey in iOS 6



Data Upload and Storage

To collect data, TravelSurvey is divided into two data collection modes, per the TxDOT data requirements. These modes are passive data collection mode and interactive data collection mode. The passive mode can collect data automatically by TravelSurvey, such as spatial and temporal data. However, the interactive mode relies on participants' response. Participants will be able to respond to questions. These questions will be divided into four categories:

- a) Household Information
- b) Profile Information
- c) Vehicle Information
- d) Trip Information

The first three categories contain one-time input questions. Trip information, however, will need to be re-entered with every trip. The questions will be shown individually under the respective category. Each data category adheres to a five-array model of interface generation:

- a) questionTitle

- b) questionDescription
- c) answerContent
- d) answerChoices
- e) categoryArray

A one-dimensional array, “questionTitle,” stores category information for each question. The other one-dimensional array, “questionDescription,” refers to the actual questions. The final three arrays determine which interface will be shown. The multi-dimensional array, “answerContent,” is structured as: “answerContent[answerChoices][answerType][keyOfDic].” The arrays are structured in this way because the answers to the questions are classified as multiple-choice selection and text input. The multiple-choice selection displays the answer choices that are organized into the array, “answerChoices.” An object, “picker view,” displays the answer choices to participants, and the participants just need to click a highlighted row to decide an answer. The text input requires participants to manually type the answer into a provided text field by keyboard. Thus, the “answerType” in the array is used to define what kind of interface will be shown on the screen. The answerType is given three values 1, 2, and 3, to flag the interface display. Number 1 defines the answer as a text input, and a text field with a standard keyboard will be generated. In this case, the array “answerChoices” is empty, so it is assigned a space as a placeholder. Number 2 classifies a multiple-choice selection, and a picker view with answer choices will be shown on the screen. Number 3 refers to a digital-only text input, and a text field with a digital keyboard will appear. “keyOfDic” is used to assign a key to each question so that the answer to the question can be saved as a value in a dictionary. Because “answerContent” is dynamically created with questions, before it is set to NULL, each “answerContent” is added into the other multi-dimensional array called “categoryArray” for use in different data categories. Figure 2 shows the three interfaces that are generated by different array structures.

In TravelSurvey, the answers are eventually stored into a property list file (plist) organized as a dictionary structure. The answers are saved as a value pairing with an identifying key from the last index “keyOfDic” in “answerContent”. The one-time input answers are immediately written into a plist. However, the trip plist, which is named tripName.plist, has to be dynamically and individually created so that each trip information can match the corresponding trip.

The method of uploading data to the database is by making an http request to the PHP web service. At the time when the PHP file receives the request, the PHP file starts to process SQL query and transfer the data to the database. The http request is produced by a string that is structured by the server address, sample number, action type, keys, and values. Participants are allowed to re-submit data if they edit the data. On the server side, if the sending sample number cannot be found in the database table, the PHP file executes SQL insert query because it is the first time for the data to be uploaded. Otherwise, it executes an update query.

THE EVALUATION OF THE APPLICATION OF TRAVLESURVEY

To thoroughly evaluate the smartphone-based method, a pilot HTS and semi-structured interview was conducted. IRB granted approval for use of a human subject for this study. In this study, there are four situations to be addressed. First, the current development tool and environment can satisfy an HTS app development. Second, the required data can be successfully uploaded to the server and saved to the database. Third, the present device can support an HTS. Fourth, the feedback from interviewees will be positive.

The semi-structured interview was considered as a direct way to collect participants' feedback about the pilot survey, and the process of the interview will help the interviewer to elicit more information detail. Additionally, because the participants are much newer users of TravelSurvey and have multiple backgrounds, they may have substantially different views from the researchers on the experience of the survey. The researcher knows how to use TravelSurvey to record data well, but the participants may think the operations are difficult to make. Thus, after the researcher previewed the raw data from the participants, the interview was scheduled with them. A recorder may be used if the interviewees permit it.

The process of the pilot HTS and Semi-Structured Interview

To make the conditions of pilot survey closer to a physical HTS, there are not any restrictions on recruitment, and any participant is welcome to download the app to take the survey if they are iPhone owners. In a typical HTS, the trips are supposed to be made within schooldays other than weekend and holidays. To encourage the participants to make trips as much as possible, they were allowed to make trips at anytime even within the weekends and holidays. All the

participants knew that they would be asked privacy information in the survey. Finally, there were eight participants who took the survey, and seven of them completed the interview that would be scheduled with the participants after they submitted their trip data. The interview questions are listed as follows:

1. What do you think of the UI design?
2. What do you think of the operations on the application, are the operations easy to make?
3. Does the survey application affect you when you make a call or write a text message?
4. What do you think of the burden of the smartphone-based method?
5. You have missed several questions, why did you not answer the questions?
6. Compared with the traditional methods, such as paper-based, do you prefer the smartphone-based method?
7. How much time did it take you to complete the survey questions?
8. Is it possible that you forgot to click “Start Trip” and “End Trip” buttons?
9. If Texas Department of Transportation conducts the survey, what are the guarantees they can make to ensure that you would provide privacy information?
10. On a scale ranging from 0-5, 5 being the highest, how do you rank the TravelSurvey?
11. Do you have any suggestions?

The Result of Evaluation

There are eight persons who participated in a one-week pilot survey and successfully uploaded the data to the server. Seven of them made at least one trip, but the other one did not record any trips due to a personal reason. One of the eight just submitted a portion of HTS data, and this person did not join the semi-structured interview. From the database, the uploaded data was correctly saved in the respective tables. On the other hand, most questions were answered, and these answers can be completely collected and successfully uploaded by smartphones.

Seven interviewees participated in the semi-structured interview after the pilot survey. A typical semi-structured interview is conducted by face-to-face; however, due to the schedule conflict between the interviewer and interviewees, only four of them were retrieved by a face-to-face interview, and the others were retrieved by telephone. Thus, the interview was not exactly a strict semi-structured interview.

Generally, their feedback is positive. They think TravelSurvey is a user-friendly app and the operations are clear and easy to make. Even if they were making a call or writing a text message, there were no impacts on them. The interviewer gave an explanation on the other traditional methods of HTS data collection to the interviewees, and these interviewees had never been exposed to the experience on the other traditional methods of HTS data collection. Compared with the other methods for HTS data collection, they still prefer the smartphone-based method.

A common negative comment from them is that the number of questions in the survey is too many, and these questions placed a burden on them to complete the survey. Too many questions may increase the missing rate. If the questions can be standardized and minimized, the burden will be reduced. Moreover, the interface design should be improved. Since some of them did not read instructions that were provided in TravelSurvey, they did not know how to use the app well. Also, they think it is possible to forget to click the “Start” or “Trip” buttons.

As for Question 9, most of interviewees would share their private information if a guarantee is made to protect their information and will not be released to anyone else except the people from the HTS project, and their information will not be used in a commercial purpose.

For Question 11, the interviewees suggest TravelSurvey should:

1. Minimize the number of questions
2. Add “Not Applicable” option into answer choices
3. Change the “Next” button to “Done” or “Save” if the questions are completed so that the user can know the questions are finished or saved
4. Be more clear with what the users should do after answering the last question in a series of questions.

THE OPPORTUNITIES AND CHALLENGES OF SMARTPHONE MOBILITY HOUSEHOLD TRAVEL SURVEYS IN TEXAS

INTRODUCTION

More than half of American adults have a smartphone (39). Smartphones have become an indispensable device in daily life. Traditional household travel survey methods including CATI, CAPI, CASI, and GPS-based have problems with providing high-accuracy data and incur high labor and time costs. Smartphone-based household travel surveys are expected to perform better in collecting trip data. There is no doubt that smartphones with a GPS function can provide more precise temporal and spatial information and reduce survey burden and cost compared with previous methods. There are several countries, such as America, Australia, Japan, and Singapore, that have already developed smartphone applications that are used for travel surveys, and pilot experiments have been conducted to investigate the advantages and disadvantages of this new method.

Although the researchers believe that smartphones will be very useful for conducting household travel surveys, their use for such still has inevitable challenges. One important challenge is the sample bias. Household travel survey data needs to be collected in a demographical and geographically unbiased way. The ownership ratio of smartphones for different age and economic groups varies. One way to ensure unbiased household sampling is still through the traditional controlled recruitment. This method does not reduce the recruitment labor cost of identifying, mailing, and calling the potential participants, especially when the enrollment rate is as low as a few percent. However, the process of enrolling and collecting data can be simplified once the participant agrees to participate with the assistance of smartphones. The other way to recruit participants is through a two-phase method: (1) in the first open recruitment phase, participants are recruited through channels such as social media; and (2) in the second phase, collected data is analyzed and the data gap is filled in to reduce bias.

Additionally, weather, signal, and app design present other challenges in using smartphones to conduct household surveys.

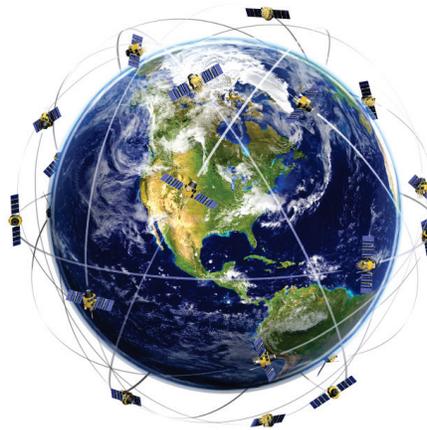
THE OPPORTUNITIES OF A SMARTPHONE-BASED METHOD

Global Positioning System

GPS is a space-based satellite navigation system that was developed and has been operated by the U.S. Department of Defense since 1973. The GPS system consists of 24 satellites that are distributed to six orbital planes with four satellites each. The system can precisely provide position, velocity, and time 24 hours a day in any weather condition, any location, and with an unlimited number of users simultaneously and free of charge.

A GPS receiver calculates its position and time by the signals that are transmitted from satellites above the earth to the ground equipment, as shown in Figure 14. The time and space calculations are based on at least four satellites, three of which calculate the position in three dimensions, and a fourth that provides the time by atomic clocks on board. However, GPS receivers require an unobstructed view in the sky. Thus, they do not perform as well within urban areas, canyons, and near tall buildings.

Figure 14. GPS Satellites and Orbits.

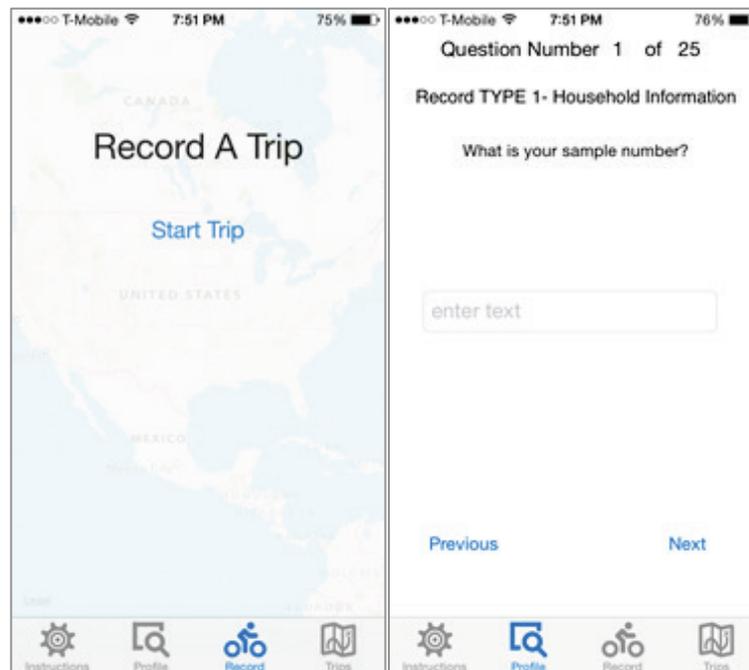


Trip data collection requires trip date, time, and location information. Traditionally, whatever the methods they use, these data points of information come from the participants' memory after each trip. In some cases, the precision of data is not satisfactory and leads to missing values. A smartphone with a GPS function cannot only provide exact temporal and spatial data but also detect routes, vehicle velocity, and trip chaining. Using the smartphone-based method, trip data includes not only origin, destination, and purpose, but other information as well.

Smartphone Development Environment

The most popular smartphone operating systems are iOS and Android (which account for 92.3 percent of all smartphone operating system shipments in the first quarter of 2013 according to the International Data Corporation). The iOS development environment is built on the Xcode platform and uses the Objective-C language. Android development is based on the Linux kernel and uses Java programming language from Google. Both of the operation systems are highly reliable on smartphones and provide a great user experience. Moreover, the professional software development kit (SDK) of iOS and Android simplify to some extent the development task. The functions in the geography and GPS library applications make it easy for developers to program trip data collection using GPS. Combined with the map library functions and location pinpoint droppings, user routes can be visualized. Figure 15 shows an interface of TravelSurvey in iOS7.

Figure 15. TravelSurvey Interface in iOS 7.



The Advantages of Data Processing

The advantages of the smartphone-based method are not only in technology, but also in data collection and processing. Data collection, storage, and transferring can be streamlined and combined with backend databases. Databases allow for data storage, filtering, deletion, querying, and more. Traditional data collection methods need more time and labor for data inputting.

Surveyors have to spend a lot of time on raw data coding, data entry, and editing. The smartphone-based method allows participants to directly enter and edit their own data through their own devices, and the data can be validated and transmitted to permanent storage automatically. In addition, trip data is recorded and sent to databases with a few clicks with the assistance of GPS and the app. Figure 16 shows a sample table showing how the HTS data is saved in a database.

Figure 16. Sample Table for Household Travel Survey.

#	Column	Type	Collation	Attributes	Null	Default	Extra	Action
<input type="checkbox"/>	1 id	int(255)			No	None	AUTO_INCREMENT	Change Drop More
<input type="checkbox"/>	2 sample_number	varchar(8)	latin1_swedish_ci		No	None		Change Drop More
<input type="checkbox"/>	3 phone_number	varchar(15)	latin1_swedish_ci		No	None		Change Drop More
<input type="checkbox"/>	4 advance_letter	varchar(5)	latin1_swedish_ci		No	None		Change Drop More
<input type="checkbox"/>	5 address	varchar(200)	latin1_swedish_ci		No	None		Change Drop More
<input type="checkbox"/>	6 number_persons	varchar(11)	latin1_swedish_ci		No	None		Change Drop More
<input type="checkbox"/>	7 number_employed	varchar(11)	latin1_swedish_ci		No	None		Change Drop More
<input type="checkbox"/>	8 vehicles_available	varchar(11)	latin1_swedish_ci		No	None		Change Drop More
<input type="checkbox"/>	9 vehicles_ownership	varchar(11)	latin1_swedish_ci		No	None		Change Drop More
<input type="checkbox"/>	10 bikes	varchar(11)	latin1_swedish_ci		No	None		Change Drop More
<input type="checkbox"/>	11 residence	varchar(50)	latin1_swedish_ci		No	None		Change Drop More
<input type="checkbox"/>	12 other_residence	varchar(50)	latin1_swedish_ci		No	None		Change Drop More
<input type="checkbox"/>	13 tenure	varchar(11)	latin1_swedish_ci		No	None		Change Drop More
<input type="checkbox"/>	14 previous_residence	varchar(200)	latin1_swedish_ci		No	None		Change Drop More
<input type="checkbox"/>	15 hh_factors	varchar(100)	latin1_swedish_ci		No	None		Change Drop More
<input type="checkbox"/>	16 other_factors	varchar(200)	latin1_swedish_ci		No	None		Change Drop More
<input type="checkbox"/>	17 income	varchar(11)	latin1_swedish_ci		No	None		Change Drop More
<input type="checkbox"/>	18 day_visitors	varchar(11)	latin1_swedish_ci		No	None		Change Drop More
<input type="checkbox"/>	19 overnight_visitors	varchar(11)	latin1_swedish_ci		No	None		Change Drop More
<input type="checkbox"/>	20 delivery_vehicle	varchar(11)	latin1_swedish_ci		No	None		Change Drop More
<input type="checkbox"/>	21 number_delivery_driver	varchar(11)	latin1_swedish_ci		No	None		Change Drop More
<input type="checkbox"/>	22 phone_service	varchar(11)	latin1_swedish_ci		No	None		Change Drop More
<input type="checkbox"/>	23 time_without	varchar(100)	latin1_swedish_ci		No	None		Change Drop More
<input type="checkbox"/>	24 hh_vehicle_use_by_nonnumber	varchar(11)	latin1_swedish_ci		No	None		Change Drop More
<input type="checkbox"/>	25 share_phone	varchar(11)	latin1_swedish_ci		No	None		Change Drop More
<input type="checkbox"/>	26 smartphone_house	varchar(5)	latin1_swedish_ci		No	None		Change Drop More
<input type="checkbox"/>	27 relationship	varchar(20)	latin1_swedish_ci		No	None		Change Drop More
<input type="checkbox"/>	28 sex	varchar(15)	latin1_swedish_ci		No	None		Change Drop More
<input type="checkbox"/>	29 ethnicity	varchar(100)	latin1_swedish_ci		No	None		Change Drop More
<input type="checkbox"/>	30 other_ethnicity	varchar(100)	latin1_swedish_ci		No	None		Change Drop More
<input type="checkbox"/>	31 age	varchar(3)	latin1_swedish_ci		No	None		Change Drop More
<input type="checkbox"/>	32 licensed_driver	varchar(8)	latin1_swedish_ci		No	None		Change Drop More
<input type="checkbox"/>	33 employment	varchar(11)	latin1_swedish_ci		No	None		Change Drop More

The Reduction of Cost

The prior methods of household travel surveys need employees to call the residents to recruit the participants and mail the travel diary to the participants. If GPS is used in the trip collection, the device delivery and retrieval leads to more cost. During the post-data processing, the analyzers have to input, code, and edit the raw data, which is expensive. This telephone and postal retrieval method to household travel surveys costs \$175 per person in Australia and \$300 per person in the

U.S.; a face-to-face method cost is estimated at \$350 per completed household. A GPS household travel survey with 850 households for 15 days would cost a total of \$425,000 (43). If a household travel survey adopts the smartphone as the tool to collect the data information, the surveyors do not have to provide extra devices to the participants. Researchers have not seen any reported costs on using smartphones for travel surveys yet. The cost reduction is mainly in the areas of (a) no need to provide an extra device, (b) no recruitment cost, and (c) no data entry and collection cost.

THE CHALLENGES OF THE SMARTPHONE-BASED METHOD

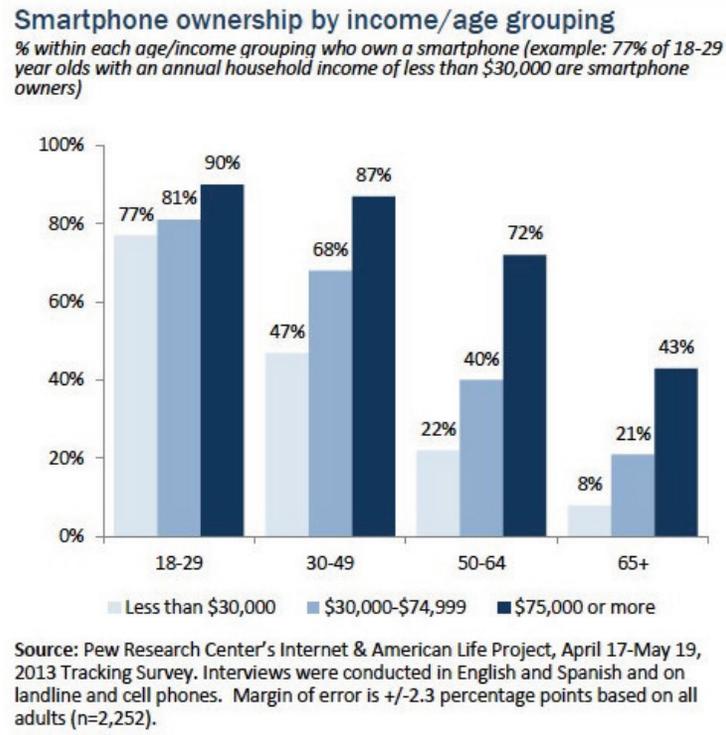
The Demographics of Smartphone Owners

Although the smartphone-based method has many advantages, the method still needs more investigation. More than half of American adults have smartphones, but still not everyone has one. Indeed, the ownership of smartphone distribution is demographically uneven, as expected. Figure 17 and Table 20 shows the distribution according to the Pew Research Center Internet Project Survey (39). The ownership in men (61 percent) is higher than woman (57 percent), and more Hispanics (61 percent) have smartphones than other races. Additionally, age, education level, household income, and community type all have effects on smartphone ownership. According to 2012 U.S. Census results, 55 percent of the Texas population is between 18 and 65 years old, 38.2 percent is of Hispanic or Latino ethnicity, and 26.3 percent has a bachelor's degree or higher (lower than the U.S. total with 28.5 percent). These characteristics should be considered and evaluated in smartphone-based travel surveys.

Table 20. 2014 Smartphone Ownership Demographics (39).

All Adults	Have a Smartphone (58%)
Gender	
a. Men	61
b. Women	57
Race/Ethnicity	
a. White	53
b. African-American	59
c. Hispanic	61
Age Group	
a. 18–29	84
b. 30–49	74
c. 50–64	49
d. 65+	19
Education Level	
a. High School or Less	44
b. Some College	67
c. College+	71
Household Income	
a. Less Than \$30,000/yr	47
b. \$30,000–\$49,999/yr	53
c. \$50,000–\$74,999/yr	61
d. \$75,000+	81
Community Type	
a. Urban	64
b. Suburban	60
c. Rural	43

Figure 17. 2013 Smartphone Ownership Demographics.



Smartphone Application Development

To use smartphones in a household travel survey, a smartphone app is required. The surveyors should know what data needs to be collected and be familiar with the functionality of the app. The interface design should consider participants' psychology and behavior, and the app should be easy to operate. Complicated operations would give participants extra burden, and participants might refuse to use. Also, the participants would be more likely to incorrectly record data and trips. Research results in physiology and persuasive technology should be used. Relevant principles that retain participants should be translated into concrete smartphone app design and functionalities.

GPS (calculation intensive) and cellular data communication consumes battery quickly in most smartphones. Battery drainage can be reduced by (a) asking participants to start and end the app before and after each trip; this method requires participant attention; and (b) using low sampling rates and adaptive sampling to allow passive recording; this method releases participants from operating their phones to record trips. A combination of significant-change location and

background location services may be used to achieve adaptive sampling. Today, many people have car adaptors to charge their smartphones while driving.

Weak Signal in Survey Region

GPS signal is not always available all the time. If the participants are passing through poor survey regions, such as in an urban area, canyon, or forest, or even under cloudy weather conditions, the GPS signal may be too weak to be detected. Additionally, in these regions, the cellular signal may not be very strong. In this case, data can be recorded in the smartphone and transmitted to the server later and an algorithm can be developed to interpolate the data between sampling points using road structures. In the worst case, a travel diary may be needed to help the participants record the trip information.

Privacy and Data Security

Household travel surveys contain a lot of private information including age, education, employment status, income, and address. The rejection rate is very high, partially because of this, and it is highly possible that the participants will question how their personal information will be used. Whether their information can be safely stored and whether their privacy will be exploited by someone are concerns. Additionally, if the data is finally saved onto a database, the security of the data transfer and storage is another concern. Access control and encrypted data transmission are recommended in smartphone-based travel surveys.

CONCLUSION

This report describes the opportunities and challenges in smartphone-based household travel survey methods. The most apparent advantage of this method is higher accuracy in temporal and spatial data collection compared with traditional methods. Furthermore, the data collection, input, and editing burden can be reduced significantly by a smartphone app. There is no need to deliver the survey equipment to the participants; therefore, the smartphone-based method is an effective and economical way to collect survey data.

The main challenges are sample bias, battery consumption, weak GPS signal in some regions, and privacy and data security. Large-scale smartphone-based travel surveys have not been performed yet, but they will likely be utilized very soon.

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