REVISED REPORT

IN-THE-MOMENT TRAVEL STUDY

RSG
the science of insight

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PREPARED FOR:
MADISON COUNTY COUNCIL OF GOVERNMENTS

SUBMITTED BY:
RSG

55 Railroad Row
White River Junction, VT 05001
802.295.4999
www.rsginc.com

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1.0 OVERVIEW

1.1 | ABSTRACT

Traditional household travel surveys (HTSs) typically collect a single day's worth of travel from a sample of residents in a region. As a result, the traditional snapshot of regional travel comprises a sample of households' travel on only a few days in any given year. A growing body of work[1] suggests that longer data collection periods are warranted to provide improved data for modeling purposes and understanding trends. However, for longer periods of data collection to be successful, all aspects of projects must be implemented with a mindfulness toward the impacts on respondent burden. Scalability is also a challenge when coupled with the demand for accurate GPS data and ever more detailed survey data for modeling purposes.

The In-the-Moment (ITM) Travel Study project, conducted by RSG on behalf of the Madison County Council of Governments (MCCOG) in Anderson, Indiana and the Federal Highway Administration (FHWA) Office of Planning and Office of Transportation Policy Studies, addressed these challenges by replacing the traditional travel diary experience with smartphone GPS data collection over a seven-day period. The smartphone's sensors passively collected location data (the "where and when" of travel data), while in-app survey questions obtain the remaining essential HTS data elements (the "why, who, and how" of travel behavior). The goal was to prompt respondents to answer these in-app survey questions in close to "real-time" at each trip destination and in a very low burden way, which facilitates the ability to conduct these projects for the longer data collection period.

1.2 | LITERATURE REVIEW

In the last several years, strong interest in smartphone-based travel surveys that collect data over a longer period of time has resulted in a number of projects outside the U.S. The best known project, the Future Mobility Survey, was a smartphone-based travel survey conducted as a subset sample of at least 1,000 participants in the nationwide Singaporean Household Interview Travel Survey (1). Participants were asked to use an Android™ or iOS™ smartphone app to passively collect their spatial and temporal travel data and then go online to validate five days of travel (prompted recall) in order to receive an incentive equivalent to $25 USD.

In Europe, recent smartphone-based GPS travel surveys have included a 2013-2014 travel survey of 1,000 participants across the Czech Republic who answered a questionnaire, then were provided with an Android™ smartphone for a two-week data collection period, and additionally completed paper travel diaries in parallel to carrying the smartphone (2). Although not currently a GPS travel survey, the German Mobility Panel annually collects seven days of travel data from approximately 1,500 households (3). In 2013, the Dutch Mobility Panel implemented a smartphone app called MoveSmarter where 600 panel members participated for a two-week period (4). Among the 600 participants, approximately 40% used their own smartphone while the rest of the sample were

[1] http://www.brookings.edu/research/papers/2015/04/17-driving-in-the-21st-century-dutzik-tomer-baxandall-puentes

provided with a smartphone, and all were asked to use a web-based prompted recall survey. Preliminary results indicate higher trip rates than previous Dutch survey methods.

In Sydney, Australia, a seven-day travel diary was conducted in 2013 with more than 600 participants (5). About half of participants used their own smartphones to passively record their travel over the seven days and then verify their trip details in an online diary where they could view maps of their daily travel. A preliminary result of the study was that users of the smartphone app were associated with higher trip reporting rates, as well as the fact that the majority (76%) of participants completed all seven days of data collection. Nearby in New Zealand, a 2014 trial of the national household travel survey was recently conducted to compare methods among web-based, handheld GPS, and Android™ droid smartphone-based GPS survey approaches (6). The group of about 70 participants who participated via a smartphone had the highest study completion rates.

Although it is clear numerous countries are on a path to implementing smartphone-based GPS travel studies that collect data over a longer period of time, very few smartphone-based GPS travel surveys have been conducted in the U.S. This is especially true when excluding U.S. smartphone apps that detect trips and primarily aim to provide users with feedback on their travel behavior rather than aiming to partially or fully replace a traditional household travel diary approach (7). Likely due in part to desires to manage project costs during recent economic downturns and to the need to test new methodologies and technologies in the U.S., U.S. surveys have largely been limited to one or two-day travel diaries in recent years using known methodologies. However, smartphone penetration rates and technological advances in smartphone technology continue to increase rapidly in the US, which garners more interest in conducting smartphone-based surveys. This paper seeks to summarize the preliminary results of quite possibly the first multiday smartphone-based GPS household travel diary survey in the U.S., which was conducted in May 2015.

1.3 | OVERVIEW

With any research project of this nature, it is important to start the project with focused goals. The project team worked together and determined the following specific project goals:

- Implement a smartphone-based household travel diary seeking to determine if such an approach is indeed a viable replacement alternative to traditional travel diary methods.
- Test an approach that will ultimately improve the quality of household travel diary data collected (closer to real-time, improved accuracy, and for much longer data collection periods), while aiming to substantially reduce respondent burden over existing travel diary methodologies.

To accomplish the project goals, the invitation pool for ITM consisted of participants from the 2014 Heartland in Motion Transportation Study, a household travel diary survey conducted for MCCOG in the spring of 2014. As is standard practice, in the 2014 study all participating households were asked their willingness to be contacted to participate in future transportation studies for the region. By re-inviting these "volunteer" households it could ultimately be possible to compare data from the household's 2014 one-day travel diary completed via telephone or web to data from the household's 2015 seven-day travel diary completed via a smartphone-based GPS app.

The project began in late fall 2014 and led to data collection in the spring of 2015. The data collection period was planned to have highly similar travel dates in both spring 2014 and spring 2015, for data comparison purposes. Following the approximately five-month planning, testing, and app development timeframe, the rMove™ app was submitted to the Android™ and iOS™ app stores in very early April 2015. In late March 2015, households were invited by e-mail to complete a web-based recruitment survey that was intentionally highly comparable to the recruitment questionnaire from the previous year. Once the app was published in both the Android™ and iOS™ stores in late April, recruited households were sent instructions for how to download rMove. The seven-day travel period occurred from May 5-11, 2015, with participants receiving reminders and encouragement throughout the process. About a week after the assigned travel period concluded, incentives were issued and a follow-up survey was sent to those who participated, those who recruited but did not download, and those who did not recruit, with a goal of determining user experience and reasons for nonparticipation.

Because key goals of the project included both obtaining data collection for a seven-day period and reducing respondent burden, the project did not ask participating households to participate by multiple means. Thus, households were not asked to complete parallel paper surveys or online surveys. Instead, the project focused on the rMove smartphone app passively collecting travel data such as the coordinates, timestamps, speed, and route of all travel during the seven-day period. Within the app, all other essential HTS questions were asked directly of the user. After stopping at a location, the app asked a short set of survey questions such as trip purpose, travel party makeup, travel mode, specific household vehicle (if auto), and travel costs. At midnight each night, a short daily survey also appeared to participants. Again, the goal was to focus on testing the future paradigm in which the entire travel survey experience occurs on the smartphone. This is in support of the theory that having respondents answer questions in real-time as trips occur and for a longer period of time will lead to high data quality.

1.4 | STUDY BACKGROUND

STUDY TIMELINE

The ITM project began in fall 2014, with data collection occurring in spring 2015 (see Table 1). Recruitment began in March 2015, and in April 2015, participants began to download the rMove smartphone application ("app") prior to the travel period dates of May 5, 2015 to May 11, 2015.

One week after the last travel date, a follow-up survey was sent to those who participated, those who recruited but did not download the app, and those who did not recruit. This follow-up survey was designed to gauge user experience and identify reasons why people did not participate in the study. A full project timeline is provided in Table 1.

TABLE 1: 2015 STUDY TIMELINE

DATE	EVENT
February 2014 to March 2014	2014 Heartland in Motion HTS and rapid transit stated-preference survey conducted online and by telephone (these participant households become the 2015 invite pool); this was a separate project
September 2014	ITM study begins
September 2014 to March 2015	rMove smartphone app feature development period
Wednesday, March 18, 2015	2015 Heartland in Motion recruitment survey open to response
Friday, March 27, 2015	Recruitment survey closed to response
Monday, April 6, 2015	rMove submitted to iTunes (iOS) & Google Play (Android) stores
Monday, April 6, 2015	Google Play Store approves and publishes rMove
Wednesday, April 22, 2015	iTunes Store approves and publishes rMove
Wednesday, April 29, 2015	Participants invited to begin downloading rMove smartphone app
Tuesday, May 5, 2015	First rMove travel date (Day #1)
Monday, May 11, 2015	Last rMove travel date (Day #7)
Tuesday, May 12, 2015	Participants sent reminders to finish any incomplete rMove surveys, instructions to uninstall rMove smartphone app
Friday, May 15, 2015	Final day that reminders and uninstall instructions are sent out
Monday, May 18, 2015	Participants invited to optional follow-up feedback survey
Tuesday, June 2, 2015	Optional follow-up feedback survey is closed to response
June 2015 to July 2015	Data preparation and documentation efforts

SMARTPHONE APP FEATURES

RSG has designed and developed several native mobile data collection platforms and authored dozens of online HTSs. This experience was combined to meet the ITM study goals. The features of the rMove smartphone app focused on a few key areas; data quality, preserving battery life, and user experience. Development of rMove—to fulfill the ITM study goals—occurred from late fall 2014 to March 2015. After several iterations of testing and improvements among the project team and select external reviewers, rMove was made available in Google Play™ and iTunes™ in early April 2015. A required support website (http://rmove.rsginc.com) was included in both store listings to provide users of the app with contact information, FAQs, and user terms and conditions.

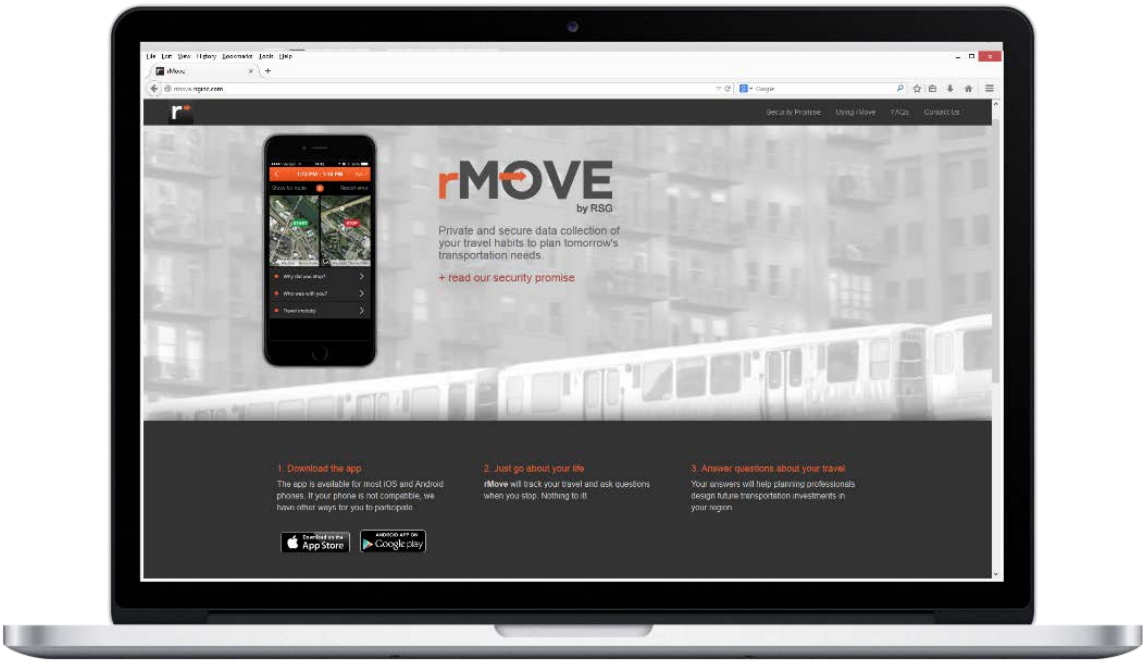
The mobile application ran natively on iOS™ 7.0 or later and Android™ 4.0 or later. Building for iOS™ proved slightly simpler than Android™, since the Android™ device ecosystem is much larger than iOS™ with thousands of unique models running Google's™ open OS globally. This is a well-understood challenge when developing apps for Android™ due to more variation in the manufacturer

hardware and the resulting Android™ OS fragmentation. The team iterated on building the application with structured software development periods, testing cycles, bug reporting, and then subsequent development cycles. An accompanying cloud service for the app's collected data was constructed with all open-source technologies, including a PostgreSQL database. In addition to the required technology coupling this provided to the rMove app, it also was a crucial study administration tool managing all study participants and household-level data, tracking missed survey responses, and displaying participant travel. Additional details and features of rMove included:

- Multiple smartphone sensors (GPS, compass, Wi-Fi, accelerometer) were utilized to automatically detect trip starts and trip ends without needing user intervention. While moving, the app also automatically recorded trip path, trip duration, and travel speed. Proprietary technology was also implemented to optimize battery life and minimize battery recharge needs, though this remains an ongoing challenge since GPS data collection is intensive for smartphones.
- To achieve a high quality user experience, the team wanted as little user intervention as necessary. To achieve this, the app automatically launched when the phone restarted and ran silently in the background. This means users did not need to start the app or select a field for data collection to occur. The app also automatically monitored the smartphone's own hardware so notifications were enabled to alert users to reactivate (or turn back on) GPS/Wi-Fi if they had been turned off.
- The rMove app was customized for each user. Participants used the same unique authorization code throughout the project; for the recruitment survey, upon download and launch of the app, and for the follow-up survey. For tracking purposes, households were given the same authorization code that they had used in the 2014 survey the previous year.
- The design of the app's user interface was based on established key features for online HTSs including a trip roster, mapping the origin, path, and destination of travel, and then providing a mobile-optimized survey to capture purpose, mode, and travel party details as appropriate. The in-app surveys and survey questions enacted many best practices from online surveys. For example, once the user was stationary at a location for five minutes (and stopped moving), the in-app trip survey appeared on the app home screen and the respondent was alerted that they had a trip survey to answer. For each trip survey, respondents were able to select which household members and which household vehicle were used on the trip. The answer choices for these questions were based on the information provided by the household in the recruitment survey. Each trip survey also had real-time validation based on the user's response. For example, if the user reported parking at the end of their trip, they were asked about parking costs.
- All collected data was automatically transferred to the server after travel was completed or a survey was completed (assuming a mobile network data connection or Wi-Fi connection). This aimed to minimize data loss in the event of a lost or damaged phone and also meant the user did not have to select a button or transfer data by their own initiative. As a best practice, all personally identifiable information was encrypted when transferring data to the server.
- Lastly, adaptive activity detection was implemented where the app learned or inferred trip survey answers based on the user's previously answered trip surveys. For example, if the user

made the same home-to-work trip, the trip survey answers were prepopulated. Users could then confirm the prepopulated answers (lower burden) or change the answers.

FIGURE 1: rMOVE USER-SUPPORT WEBSITE



Each of the rMove features listed in Table 2 were available in the April 2015 version of the app.

TABLE 2: rMOVE FEATURE LIST

FEATURE
• Fully compatible with both Android and iOS operating systems (estimated as 96% of total smartphone market share)
• Automatic trip start and end/stop detection—no user intervention is necessary
• Automatic recording of trip path, duration, and speed
• Multiple smartphone sensor utilization (e.g., GPS, compass, Wi-Fi, accelerometer)
• Automatic loading and running—app runs in background and on device power-up
• Automatic monitoring of smartphone hardware—request-to-reactivate notification if GPS/Wi-Fi disabled
• Proprietary GPS collection technology optimizes battery life and reduces recharge needs on travel days
• Automatic transfer of collected data to server after each trip is complete (assuming a connection)
• Encryption of all personally identifiable information when transferring data to server
• Companion rMove support website with FAQs and additional study information
• Customizable in-app trip survey triggered automatically by trip stop—no user intervention necessary
• In-app customization—each household selects household members and household vehicles on trip
• Ability to retain the household password and participate via new/different smartphone
• In-app trip survey includes validation and real-time logic based on user response (e.g., a transit trip is asked a question about transit fare payment, but other travel modes are not shown this question)
• In-app trip survey allows reporting of feedback and any details about trips (e.g., situations where user reports wanting to merge two trips)
• An “end-of-day” summary survey to obtain overall behavior, including reasons why no trips were made and to obtain any trips missed that day
• Adaptive activity sampling—app integrates learning or inference based on previously answered trip surveys and the user can confirm the prepopulated answer (lower burden) or change the inference

2.0 RECRUITMENT

2.1 | RECRUITMENT SURVEY

The invitation pool for ITM consisted of participants from the 2014 Heartland in Motion Transportation Study, separately conducted for MCCOG in spring 2014. In the 2014 study, 1,781 households indicated that they were willing to be contacted about future MCCOG studies, and of those, 1,427 provided a contact e-mail address. These 1,427 households comprised the invitation pool for the ITM study, outwardly referred to as the "2015 Heartland-in-Motion Transportation Study" to ensure brand continuity for the study participants.

The invitation pool of households was sent an e-mail inviting them to re-take the online recruitment survey. In order to determine which households were eligible to participate using rMove, the recruitment questionnaire collected updated household demographics and smartphone information. This recruitment questionnaire intentionally closely mirrored the 2014 Heartland in Motion recruit questionnaire, and was therefore consistent with a standard recruitment survey for a household travel diary project.

Variables collected in the recruitment survey included the following:

- Household vehicle count and details (make, model, year)
- Household size
- Household member details (age, gender, employment, education, smartphone ownership, licensed driver status, vehicle most often used, etc.)
- Housing type and tenure
- Home location
- Household income
- Contact information for members age 16 or older

Specific changes between the 2014 and 2015 recruitment questionnaires was that the 2015 recruitment questionnaire had:

- New questions to obtain person-level smartphone ownership details
- New questions to obtain person-level contact information (e-mail, phone)
- Exclusion of questions about previous home location that were included in the 2014 questionnaire for land-use modeling purposes

2.2 | RESPONSE TO RECRUITMENT

The recruitment survey was open for 10 days in late March 2015. E-mail invitations were sent to the pool of 1,427 households. Responses to the recruitment survey, specifically smartphone ownership details, determined the eligibility of a household to be invited to download rMove and participate in the study. Only Android™ and iOS™ smartphones were eligible for the study, and those persons that did not have a smartphone or those that owned a Blackberry or Windows smartphone were not eligible for the study.

In order to facilitate a larger sample size, if at least one household member had an eligible smartphone, then the person (and therefore their household) was invited to participate. In other

words, it was not a requirement that all adults within a household own a qualifying smartphone. Within each household, only members with an eligible smartphone were asked to download rMove and participate for the week of data collection. In total, 256 persons with Android™ phones and 256 persons with iPhones recruited into the study.

Table 3 shows the smartphone ownership status reported at the person level in the recruit survey.

TABLE 3: 2015 RECRUIT SURVEY RESPONSE—TYPE OF SMARTPHONE OWNED (PERSON LEVEL)

TYPE OF SMARTPHONE OWNED	PERSONS	PERCENT OF SMARTPHONE OWNERS	PERCENT OF TOTAL
Android	256	49%	43.5%
iOS	256	49%	43.5%
Other (e.g., Blackberry)	11	2%	2%
Total persons with smartphones	523	100%	--
Does not have a smartphone	66	--	8.3%
Total	589	--	100%

Among the 256 persons with an iPhone were 34 people with older phones produced mid-2010 or earlier and therefore lacking the requisite sensors for optimal use of rMove. These individuals with older Apple™ phones were not invited to the study. In the end, 222 iPhone users were invited. Because there are numerous Android™ smartphones (particularly when compared to iPhone models), the project team decided to invite all Android™ owners to download rMove and participate in the study for the week of assigned travel.

At the conclusion of the recruitment process, 478 people from 288 households were invited to download rMove. Selected participants represent 75% of the households that completed the recruit survey and 20% of the households that received the initial invitation to take the recruit survey. Of the eligible participants, those in 2-person households made up 36% of participants while 12% were in 1-person households. Over half of eligible participants were in 3-person households or larger.

TABLE 4: RECRUIT SURVEY—ELIGIBLE PEOPLE PER HOUSEHOLD SIZE (PERSON LEVEL)

HOUSEHOLD SIZE	ELIGIBLE TO PARTICIPATE	INELIGIBLE TO PARTICIPATE	PERCENT OF TOTAL ELIGIBLE
1 person	57	0	12%
2 people	172	36	36%
3 people	101	58	21%
4+ people	148	191	31%
Total	478	285	100%

2.3 | rMOVE INVITATION DISSEMINATION

RSG sent an e-mail to the 478 invited participants asking them to download rMove to their smartphone. These 478 invited participants lived in 288 households with other family members (e.g. children, in-laws, etc.) totaling 763 people in all. The invitation was sent on April 29, 2015 and included participation information such as the authentication code, the first day of assigned travel, the last day of assigned travel, download instructions for both iOS™ and Android™, and the rMove website link for FAQs and other information.

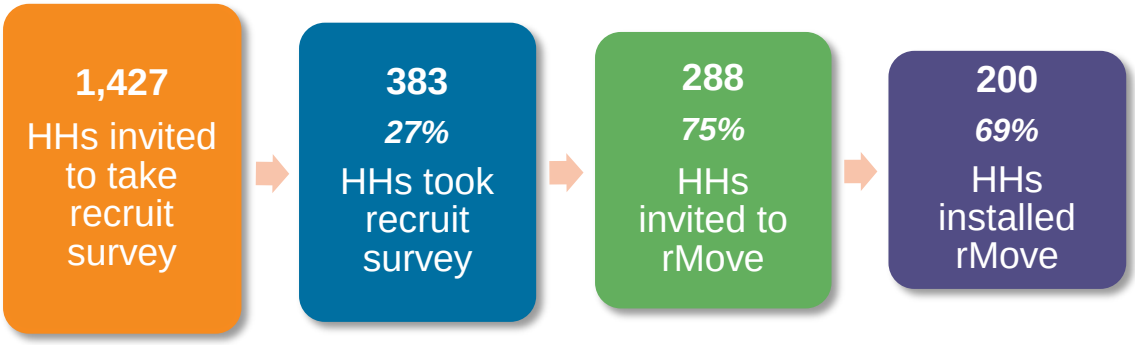
To achieve continuity and simplicity in data monitoring and database preparation, households were assigned the same unique authentication codes that they had used for the recruit survey and for the previous year's HTS. The authentication code was required when downloading rMove for the 2015 study. The authentication code served two purposes: 1) ensured that the public—outside of the set of study participants—did not download and participate in rMove studies; and 2) allowed inclusion of custom in-app details of household members and household vehicles for selection in the trip surveys. Once the authentication code was entered after downloading the app, then the participant could select her identify among the list of their household members (if they were in a multiparticipant household).

Following the initial invitation e-mail on April 29, reminders to download rMove were sent to those who had not yet downloaded the app on May 1, May 3, and May 4; these reminders were sent until assigned travel dates began on May 5. On the day before the first travel date (May 4), those who had already downloaded rMove received a brief reminder e-mail that surveys about trips would start showing up the next day.

On May 5, 2015 (the first travel date), 275 participants in 186 households had downloaded rMove, representing 57% of people and 65% of households invited to download rMove. Over the following six days of the travel study, that number rose to 295 participants in 200 households, indicating that 23 participants downloaded rMove after the travel period officially began on May 5, 2015. Overall, the study included 168 households in which every eligible member downloaded rMove and 32 households in which some but not all eligible household members downloaded rMove (200 total households).

Figure 2 shows the count of households at each stage of recruitment, from the initial invitation to installation of rMove, and the percentage of households who progressed from each stage to the next.

FIGURE 2: HOUSEHOLD RECRUITMENT PER EACH STAGE



Of the 295 participants in 200 households who downloaded rMove, just more than half of these participants used Android™ devices (154 participants, 52%), with the remaining 141 (48%) using iOS™ devices. It is worth noting that these percentages are similar to the recruitment ratio and likely indicate that Android™ and iOS™ users had similar experiences downloading and launching rMove.

TABLE 5: rMOVE PARTICIPANT SMARTPHONE TYPE (PERSON LEVEL)

DEVICE TYPE	PARTICIPANTS	PERCENT
iOS	141	48%
Android	154	52%
Total	295	100%

2.4 | RECRUITMENT DEMOGRAPHICS

Household demographics from the 2014 study ("2014 HTS") are compared to the initial 2015 recruitment pool ("2015 Recruited") and to those who went on to download rMove ("2015 Downloaded") in Figure 3 through Figure 6. The demographics for households who downloaded rMove represent households where at least one person downloaded the app, and is therefore based on 528 participants (295 of which were eligible rMove participants) in 200 households. Demographics from the 2014 study are based upon the final study sample of 1,926 households. A chi-squared test of proportions was conducted for the 2014 and 2015 data. It was expected that, due to differences in selection process, the pool of 2014 study participants would not have identical characteristics as the pool of 2015 study participants.

One- and two-person households represented a higher percentage of the sample in the 2014 HTS compared to the sample who downloaded rMove in 2015 ($p < .0001$). One possibility for this difference is that senior adults are more likely to live in one- or two-person households and are less likely to own smartphones. Similarly, the person-level age results show that people ages 65 and older have lower representation in the sample of 2015 participants who downloaded rMove than in the 2014 sample ($p < .0001$) while people 25-44 years old make up a higher percentage of the sample in the 2015 rMove download pool compared to the 2014 HTS sample ($p < .0001$). This is of interest, because traditional approaches to HTSs tend to have over-representation among older ages (and smaller household sizes) and lower-than-desired representation among younger, working age groups.

FIGURE 3: NUMBER OF PEOPLE IN HOUSEHOLD (2014–2015)

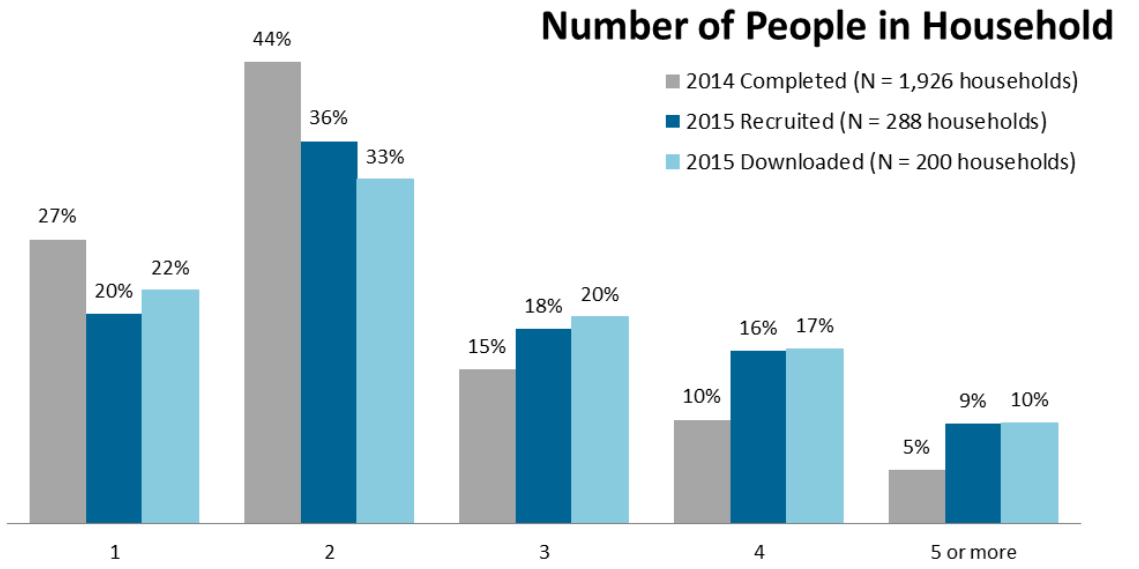


FIGURE 4: SELF-REPORTED HOUSEHOLD INCOME (2014–2015)

In 2014, households with annual incomes below $50,000 comprised a larger portion of the sample than in 2015 ($p < .0001$). Additionally, people in households that recruited in 2015 are more likely to have bachelor's or graduate degrees than those in the 2014 HTS ($p < .0001$). These demographic differences between the HTS sample and the rMove pool reflect trends reported in the 2015 U.S. Smartphone Use study conducted by Pew Research Center, which found that adults age 18-50 with higher education and income levels have the highest smartphone ownership rates.

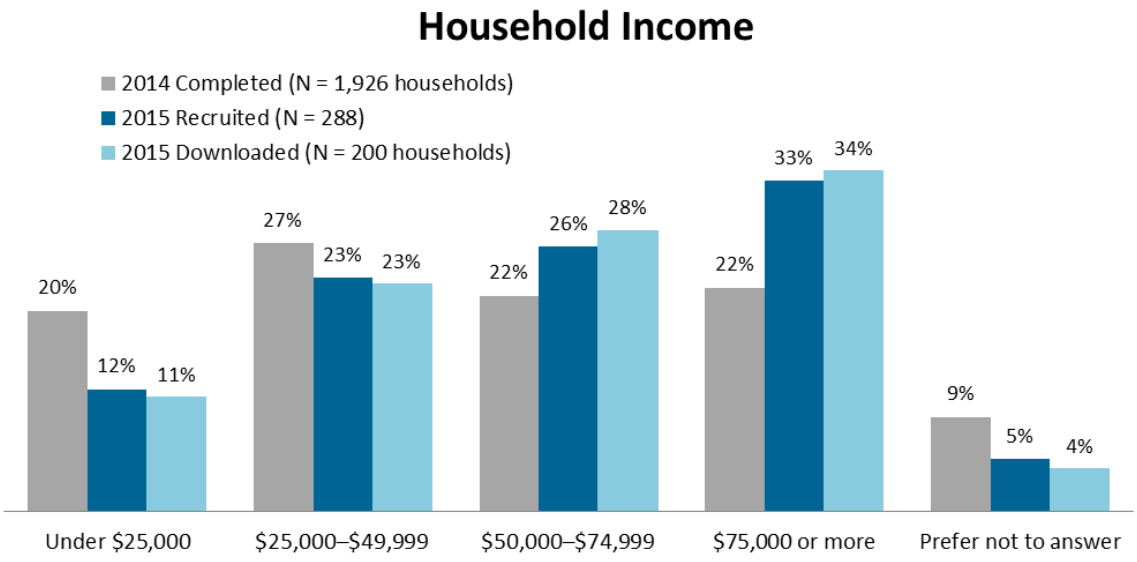


FIGURE 5: EDUCATION LEVEL (PERSONS AGE 18 OR OLDER) (2014–2015)

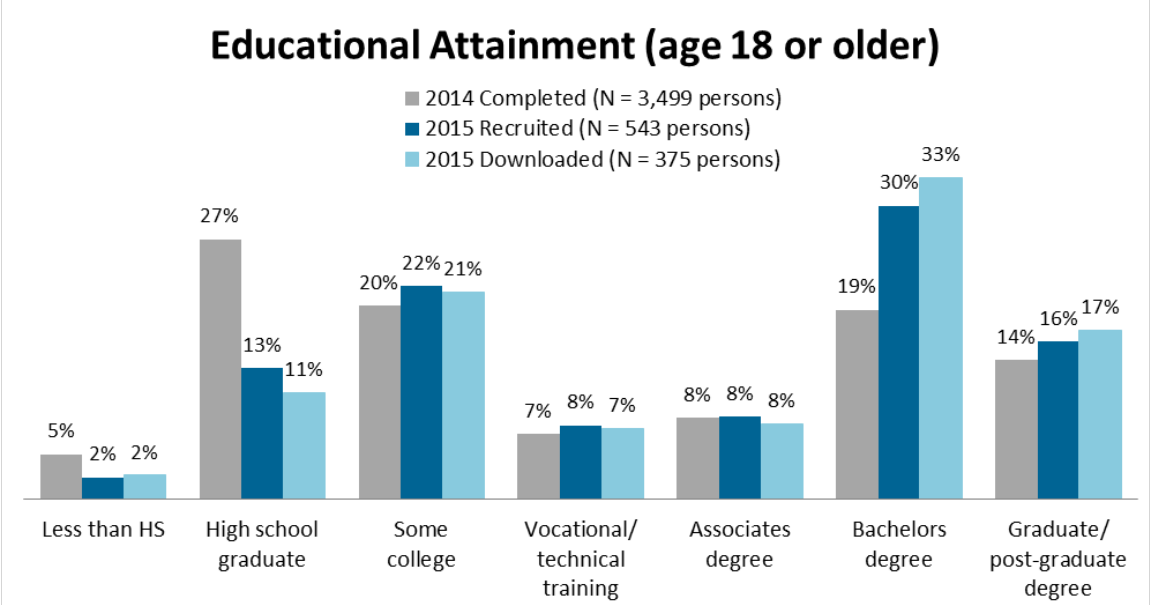
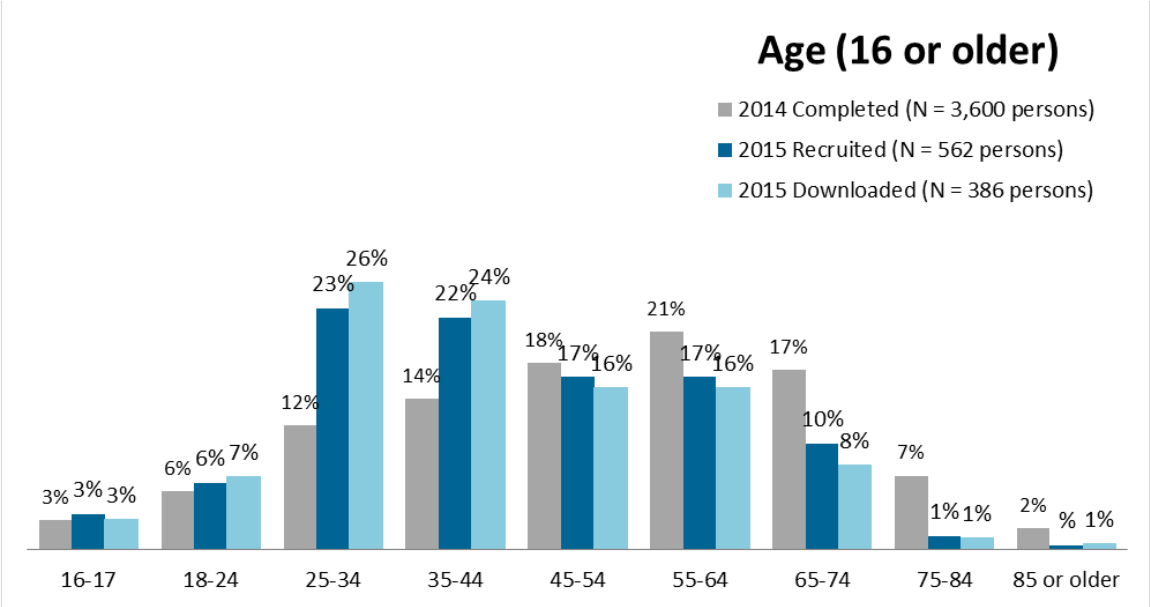


FIGURE 6: AGE OF PARTICIPANT (PERSONS AGE 16 OR OLDER) (2014–2015)



3.0 TRAVEL DIARY DATA COLLECTION

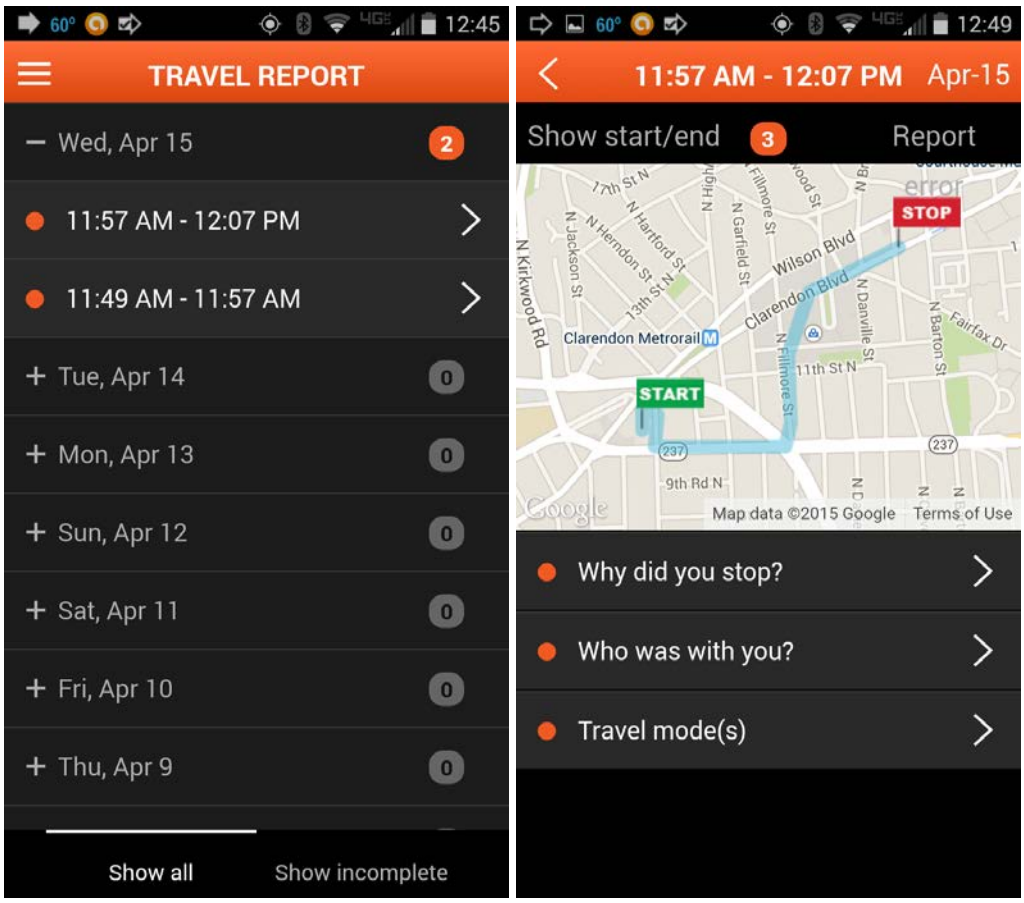
3.1 | DATA COLLECTED THROUGH rMOVE

In addition to collecting location data from devices, rMove collected user-provided responses through two types of surveys: trip surveys (for each trip made) and daily summary surveys (one survey per day).

Trip surveys appeared in rMove shortly after the app sensed that a trip had been completed. A notification popped up letting the user know each time a survey appeared in rMove. Surveys were labeled with the trip timestamp, and once the survey was selected, a map of the trip was shown, followed by trip-level questions. Once travel mode was chosen, additional questions (as relevant) were asked.

Figure 7 shows an example of the rMove "home screen" with the list of surveys, and the trip survey page with the initial questions that showed up in the trip survey. Once a mode was chosen, additional questions appeared when relevant.

FIGURE 7: rMOVE INTERFACE



Trip survey questions included:

- Trip purpose
- Trip party
  - Household members listed by name
  - Number of nonhousehold members
- Trip mode (can select more than one mode)
- Auto details, if auto mode
  - Which vehicle, if personal vehicle

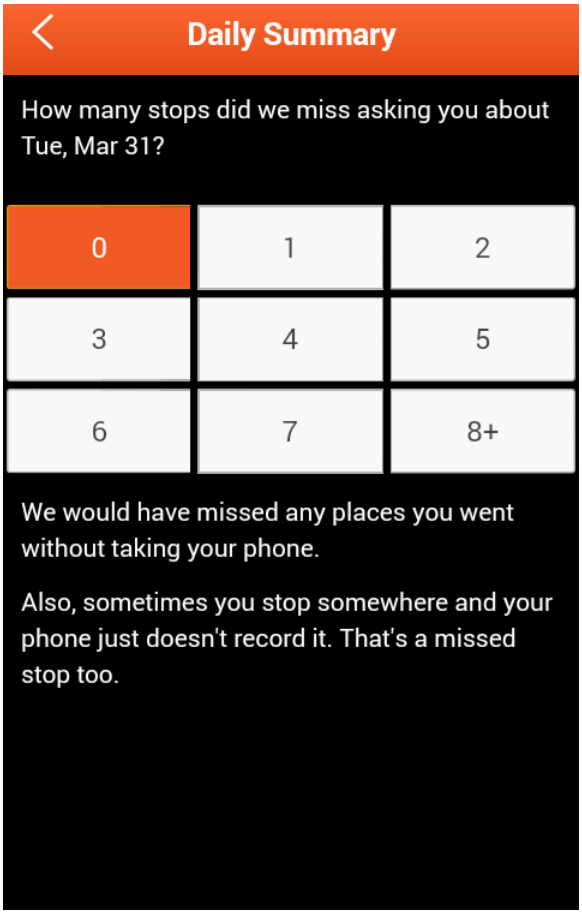
  - Type of parking
  - Parking payment

- Transit fare payment amount and method, if transit
- Taxi fare payment amount and method, if taxi

rMove recognized "repeat" trips using an algorithm to see if the start and end location closely matched the start and end location from a previous trip in the study period. When this type of trip was recognized, rMove inferred the trip details and asked the user to confirm or change the survey answers. These trip surveys were called "matched trip" surveys.

"Daily summary" surveys appeared in the app once per day at midnight after the travel day was complete. If the user traveled during the travel day, the daily summary asked one question about how many trips (if any) rMove missed during the travel day. If the person's phone did not record any travel for the travel day, the daily summary survey first asked if rMove missed any trips, and if no missed trips were reported, the survey asked why the user did not travel that day.

FIGURE 8: rMOVE DAILY SUMMARY SURVEY



The data provided from these surveys, along with the location data for each trip, were all sent to the rMove server whenever trip and survey completions were recorded by rMove and there was a connection for transmitting data.

3.2 | COMMUNICATION WITH PARTICIPANTS

Throughout the study period, several lines of communication existed between participants and RSG: participants could e-mail the project e-mail address, submit feedback through the rMove app, and RSG could send outgoing e-mail communication to users when necessary.

INCOMING COMMUNICATION

Communication from participants through e-mail and in-app feedback is quantified by type in Table 6. Participants submitted 47 comments through the feedback button within the rMove app and sent 71 e-mails related to any aspect of the study. These numbers include cases where multiple comments and/or e-mails were submitted by the same participant, so they are not reflective of the total number of participants who submitted feedback or sent e-mails.

Questions about when to uninstall the app and whether the participant qualified for the gift card incentive were the most common type of communication received, followed by technical support questions (such as lack of clarity for how to close out of the app). The "Survey questions" category mostly comprised users asking how to define a purpose or mode for different types of trips, or how to find certain options for trip details in rMove surveys. Communication about trip errors primarily concerned spurious trips recorded by the app when a person with an Android smartphone was not traveling.

TABLE 6: INCOMING 2015 rMOVE PARTICIPANT COMMUNICATION

CATEGORY	TOTAL	PERCENT
Uninstalling/study completion	26	23.4%
Technical support	17	15.3%
Eligibility	15	13.5%
Survey questions	13	11.7%
Other	11	9.9%
Comments	8	7.2%
Missed trips	8	7.2%
Trip errors	7	6.3%
Battery	6	5.4%
Total	111	100%

OUTGOING COMMUNICATION

Outbound communication with participants—other than responses to incoming communication—was primarily intended to avoid participant attrition while not being so frequent as to potentially annoy participants. Outbound e-mails were sent to participants in the following situations:

- Their smartphone had not sent any trip data to the server
- Trip surveys had not been answered recently and were "queuing up"
- After the end of the assigned travel date period, not all in-app surveys had been answered
- All surveys were complete and RSG confirmed that the user could uninstall and would receive their incentive shortly

Sixteen participants' devices did not send any trip data to the rMove server at any point during the study (and thus no data were observed via the dashboard during data collection) for various reasons, likely including the following:

- A person made no trips during travel days, resulting in no trip survey data.
- The device was a tablet and did not accompany the user on trips.
- The device's GPS or Wi-Fi sensors were turned off.
- The device had a custom operating system installed (an operating system not released by Apple or Google). This is commonly referred to as "rooting."
- The user uninstalled rMove before the travel period began or early in the assigned travel period.

If the device was a tablet, or if the user was not making any trips, this information could typically be determined through the dashboard, where a user's device type and "daily summary surveys" listing reasons for no travel could be viewed. Users with tablet devices were asked to either install rMove on a smartphone or take their tablet with them on all travel. Participants who installed rMove on smartphones but who did not send any trip data to the server on the first travel date were reminded to turn Wi-Fi and GPS on and turn "battery save" modes off.

4.0 PARTICIPATION RESULTS

Overall, 240 participants fully completed (by answering every question) every survey in rMove for all seven assigned travel days. At the household level, 138 households fully completed the study (prior to data cleaning), accounting for 82% of households where every participant downloaded rMove and 89% of all people who downloaded rMove.

This section focuses on the 270 participants in 182 households whom RSG determined were active participants during data collection (whether they fully completed the study or not), out of the 295 people from 200 households that initially downloaded rMove. Sixteen participants had devices that never sent any trip data to the database, and nine participants were determined to have started later in the travel period and are missing travel days.

4.1 | TRIP SURVEY COMPLETION

Overall, 240 participants fully completed (by answering every single question within every survey) all surveys in rMove for all seven assigned travel days. At the household level, 138 households fully completed the study (prior to data cleaning), accounting for 82% of households where every participant downloaded rMove and 89% of all people who downloaded rMove.

The clear majority (89%) of participants completed all trip surveys in the app, and only a small percentage (5.6%) completed less than two-thirds of their rMove surveys. This statistic of nearly 90% of people answering every single trip survey for seven consecutive days is encouraging for the viability of longer data collection periods. In many ways, a smartphone-based survey faces the same primary challenge that telephone or web surveys face; the biggest hurdle is the initial step to get the household to participate. By comparison and recognizing a somewhat different selection process, the 2014 study sample had an overall 81% conversion rate, whereby just over four out of five households that recruited went on to fully complete the household travel diary.

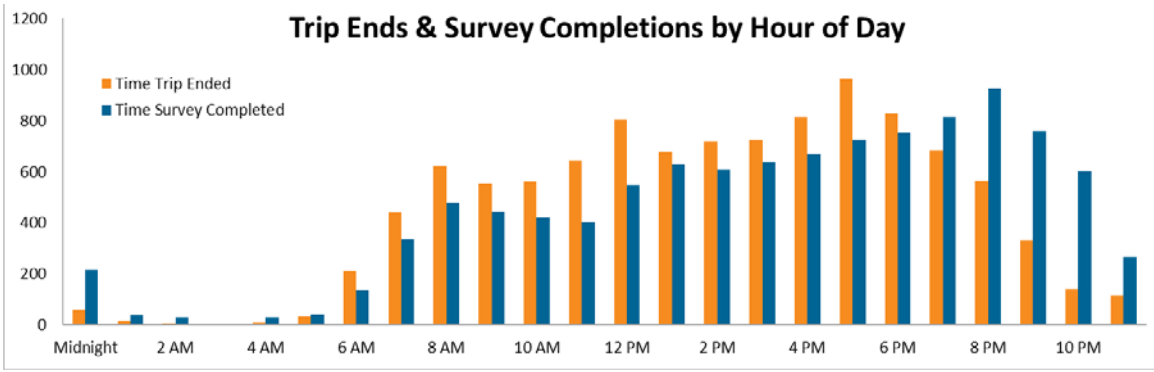
TABLE 7: PARTICIPANT-LEVEL TRIP SURVEY COMPLETION RATE

PERCENT OF SURVEYS COMPLETE	COUNT OF PARTICIPANTS	PERCENT
0 to 33%	9	3.4%
33% to 66%	6	2.2%
66% to 99%	15	5.6%
100%	240	88.8%
Total	270	100%

4.2 | TRIP SURVEY TIMESTAMPS

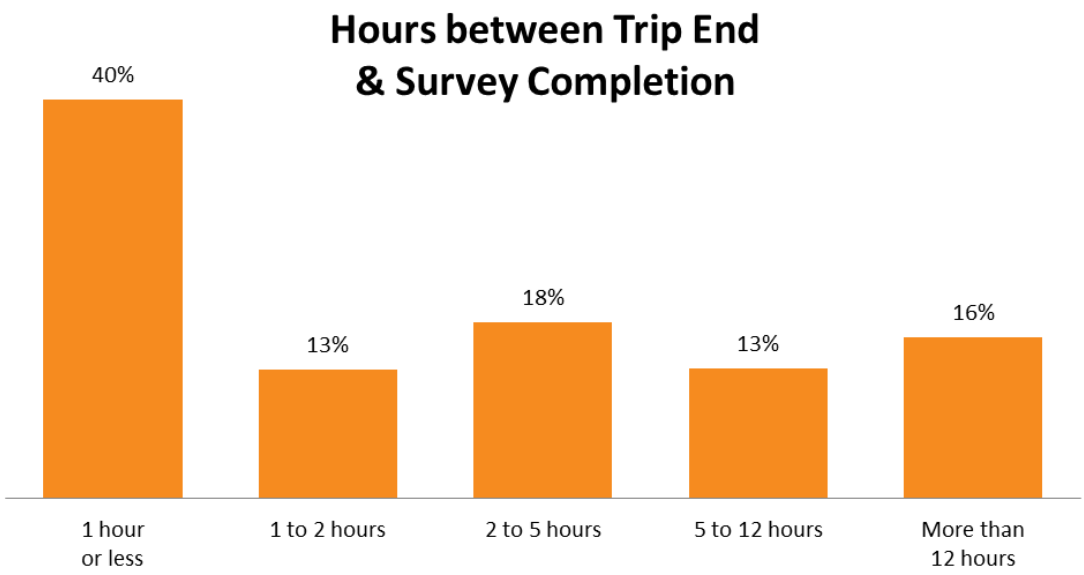
For trips where surveys were completed by the user, surveys were generally answered either within a few hours of the trip or after the participant's travel was appeared to be done for the day. Figure 1 shows the hour of the timestamp for trip ends and survey completions for all trips that had surveys answered and were not reported as "not moving" errors. While trip totals peaked during the morning, noon, and evening rush hours, the highest rates of survey completion occurred between 7:00 p.m. and 11:00 p.m.

FIGURE 9: TRIP ENDS AND TRIP SURVEY COMPLETIONS BY HOUR TIMESTAMP



Although the survey completion peaked in the evening, 40% of surveys were completed within one hour of the trip ending and 71% of surveys were completed within five hours of the trip ending. The median time between trips and surveys was 1.71 hours, or 102 minutes. Seventeen percent (17%) of surveys were completed within 10 minutes of the trip end.

FIGURE 10: TIME BETWEEN TRIP END AND TRIP SURVEY COMPLETION



In summary, the high retention rate and the short period of time that elapsed for most trips before survey completion are positive indicators that the goals of the study were at least partially met. The household retention rate of 82% is similar to that of the 2014 HTS, which was 81%, even though the travel reporting period was much longer (7 days instead of 1 day) for the 2015 study. This indicates the potential for additional burden reduction in the future as rMove's functionality improves and as people obtain ever newer, advanced smartphones. Additionally, the short period of time between most trips ending and trip survey completion indicates that the trip details reported by the participant are likely to be more accurate. This time period compares favorably to the latency in traditional online and phone surveys, where typically the project team sees about 85% of households completing their travel diary within three days after the assigned travel date.

4.3 | MATCHED SURVEYS

The "repeat trips" feature, in which rMove recognized matched trips and inferred survey answers, aimed to decrease burden for users who frequently traveled between the same locations (such as a trip from home to work). Overall, rMove recognized 951 "matched" trips. Of these, users retained 641 of the inferred surveys without changing the answers (68%), while 302 (32%) of the inferred surveys had at least one answer choice edited by the user. The fairly high level of "correct" survey inferences indicates a moderate success in burden reduction, although the overall number of trips that were recognized as "matching" trips is only 8.4% of overall trips where users filled out surveys. Therefore, further opportunity exists to improve this matching experience for users.

5.0 TRAVEL RESULTS

5.1 | RMOVE DATA PREPARATION

The trip and location data from rMove were cleaned and processed in two stages. First, all rMove data was first copied into a new database; this was done in order to preserve the raw rMove data in its original form. Second, this copied dataset was then loaded into an interface where RSG could review each participant's trips spatially on a map. All trips were individually reviewed using a web dashboard that visually displayed every detail (survey questions, trip trace, and meta-data such as timestamps). As part of the review process, a cross-check was also used to determine if the participant had reported an error as part of the trip survey.

At the conclusion of data collection and prior to any review or data cleaning, there were 10,196 trip surveys that users had answered over the seven-day period. The database also had a total of 3,443 trips that were unanswered trip surveys, for a total of 13,639 trips for review and quality control. The following processes were performed at this stage:

- All points with unrecorded speed and heading data were removed from the location data, except for points that were the origin or destination point of a trip.
- Based on spatial analysis and respondent error reporting, analysts removed trips that were false (spurious) trips, split trips with more than one clear stop, and merged trips where two or more trip traces were clearly part of the same trip.
- Trips were automatically derived when a gap of 250 meters or more existed in a person's trip record, using the previous destination and the next trip's origin as the origin and destination points of the derived trip.
- Distance along the GPS path was automatically derived.

In total, 1,766 trips resulted from splitting trips and 122 trips resulted from merging trips. Additionally, 843 trips were derived due to gaps in trip records. The dataset with the aforementioned edits was then exported, and further processes were performed on the dataset without manual spatial review of trips. These procedures included the following:

- Trips were derived for non-rMove participants in households based on whether non-rMove household members were reported as part of a trip party. (Example – a father reports his six-year-old daughter on a trip and a trip for his daughter was derived).

- Trip counts were added to person and household records.
- A "missing data" value was derived where trip or daily summary survey details were missing.
- Various other data correction and cleaning was done at this stage on a case-by-case basis.

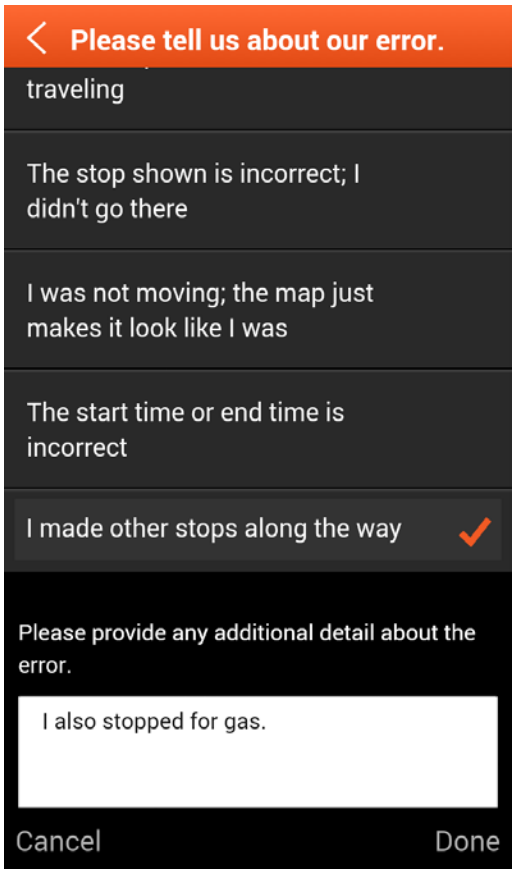
5.2 | RMOVE RESULTS OVERVIEW

Following data cleaning and review, the dataset retained 191 unique households and 283 adults who sent any amount of data to rMove from their smartphone (whether they completed all their surveys or not). Moreover, the cleaned dataset included 9,417 trip surveys that users had answered over the seven-day period, reflecting a reasonable decrease in answered trip surveys due to trip merging and removal of spurious trips from a small number of Android devices.

The number of unanswered trip surveys decreased by two-thirds to a total of 1,180 trips in the dataset without survey answers. This decrease of 2,263 trips included 1,892 trips where both the user reported a spurious trip and review confirmed the spurious trip. When considering these 1,892 trips across seven days for almost three hundred participants it yields an average of just under 1 spurious trip per day for participants. The remaining 371 unanswered trips that were removed during data cleaning were primarily also spurious trips that the server captured but rMove did not display to the user. In many ways, this result is what the project team had intentionally aimed for in the sense that having slightly too many false positive trips in the dataset was preferable to potentially erring toward missing trips and having the app not capture them.

Among the daily surveys, 97% were completed by participants for a total of 1,830 complete daily surveys. The first question of the daily survey asked the user to report how many trips rMove had missed that day. Reasons for that rMove may have missed recording a trip include both user error (forgot to take smartphone with them) and technology error (where rMove didn't record a trip despite the person making one). Among the completed daily surveys, 82% reported that rMove had not missed recording any trips and fully captured their travel on the given day. An additional 13% of daily surveys indicated that rMove had missed 1 or 2 trips during the day, while 1.7% of daily surveys indicated that five or more trips had been missed on a given day. Of the daily summary surveys completed by users, 6.8% were reported as days where no travel occurred and on the first day of travel (a Tuesday), 5.1% of participants reported the day was a "no travel" day.

FIGURE 11: SCREEN TO REPORT ERROR (USER CAN SCROLL)



TRIP RESULTS COMPARED TO 2015 WEB-BASED DIARY

Overview

Given that this was a "first" project, some considerations arise in comparing results across years. First, the 2014 diary-based household travel survey did not obtain smartphone ownership for households and persons (at the time it was not known that a follow-on study using smartphones would be conducted in 2015). Unfortunately, this means that comparisons to 2014 data currently use the entire 2014 sample because there is no ability to only use a known sub-sample of 2014 smartphone-owning households. Resulting implications are that this section likely compares an rMove sample with more younger and employed households to a 2014 diary-based sample of older households (with more retirees). This is likely a strong contributing factor in why this section shows more work trips, walk trips, and peak hour trips for the 2015 rMove sample than for the 2014 diary-based sample. It might be possible for follow-on analyses to weight the 2014 data so it has the same age distribution as the rMove sample, and then make comparisons, but this was outside the scope of the current project.

Second, with a multi-day study (here seven consecutive days in May 2015), a new complexity emerges with regard to which persons and households are considered complete for analysis purposes. Different scenarios emerge, where a subset of participants are active for some but not all days in the study (and these days are not necessarily consecutive). In future work, an initial suggestion is to

assign a person-level completion status per day, as well as a household-level completion status per day (based on the person-level completion statuses of the given household members). This would allow more data in aggregate to be included in analysis, but also allow for exclusion of a given day (say where a member of a household broke their phone and thus dropped out of the study).

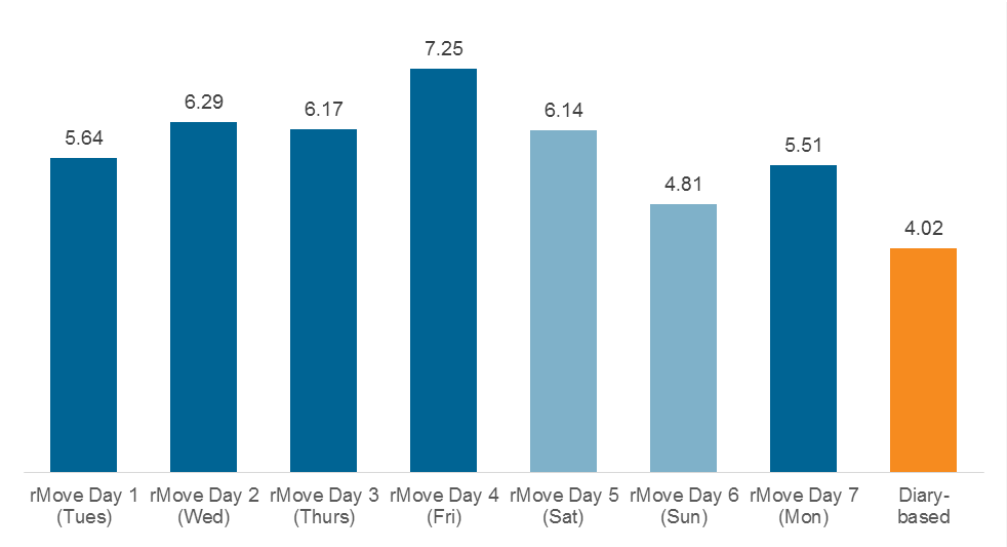
For the remainder of this section, the analysis has been restricted to the 177 rMove participants who fully completed the seven days of the study. Moreover, the analysis has then been restricted to the participation data for the Tuesday-Thursday of the study period because Tuesday-Thursday were the same days of the week that were used in the 2014 study. However it should be noted that 177 persons is a relatively small sample size and possibly a self-selective group. Additionally, in traditional diary-based multi-day surveys (most commonly two-day travel diaries), it is known that lower trip rates occur on subsequent days compared to the first, presumably due to respondent burden and fatigue. For the rMove pilot, every person started their 7-day period on Tue, so it is not possible to separate possible survey duration effects from day-of-week effects. However, as shown below, there is certainly no evidence that rMove trip rates decline during the week, with Tue, Wed and Thu all showing similar trip rates.

Lastly, although obvious, it should be noted that for the purpose of this report, RSG used the dataset provided to MCCOG in 2014. However, we assume subsequent data preparation or cleaning means that MCCOG is using an updated dataset over the one used for this analysis.

Comparison of 2014 to 2015 Results

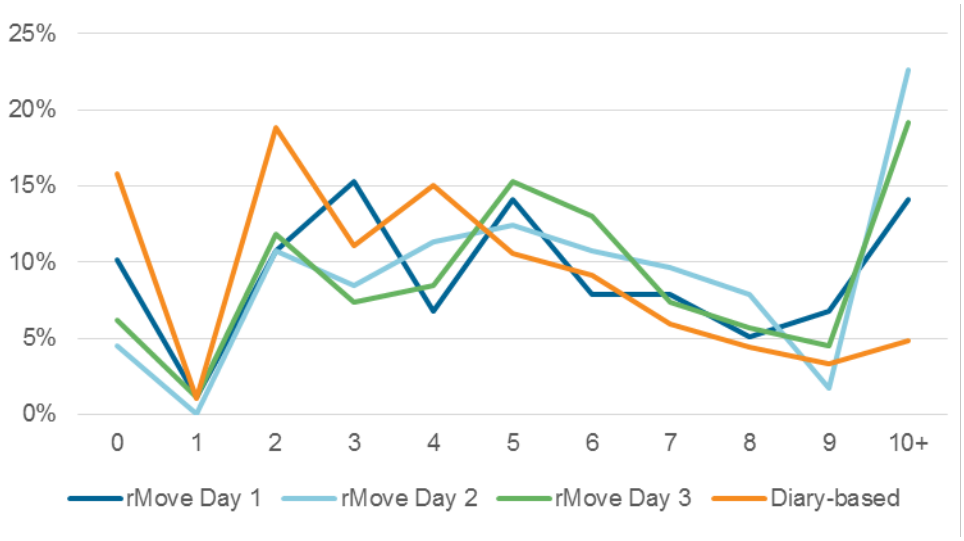
Figure 12 shows that the one-day diary-based survey, (conducted only for Tue-Thu travel days during spring 2014) yielded an average of four trips per person-day, while the rMove data has more than five trips for every day but Sunday, with a high of more than 7 trips on Friday. Weekdays in the rMove dataset had five to just over six trips per person-day. These early results indicate that the smartphone-based method yields about 25% more trips per person-day compared to the diary-based trip rates.

FIGURE 12: MCCOG PILOT SURVEY- COMPARISON OF AVERAGE TRIPS/PERSON-DAY FROM THE DIARY-BASED 2014 TRAVEL SURVEY AND EACH DAY OF THE 7-DAY 2015 SMARTPHONE-BASED SURVEY (RMOVE)



One possible reason for the higher trip rate is that fewer respondents neglect (or forget) to report any trips at all in any given survey day. Figure 13 shows that for about 15% of person-days (remember for all adults, not just smartphone-owning adults) in the 2014 diary-based data, respondents did not report any trips at all. For each of the three travel days with rMove, only about 5% of respondents did not make any trips at all. This is an indication that the cases of non-trip-making in diary-based methods are at least in part due to nonresponse bias, where people make some trips but do not report them. It should be noted that the first day of rMove data has a higher rate of zero-trip days, which might reflect some participants downloading and starting the study late.

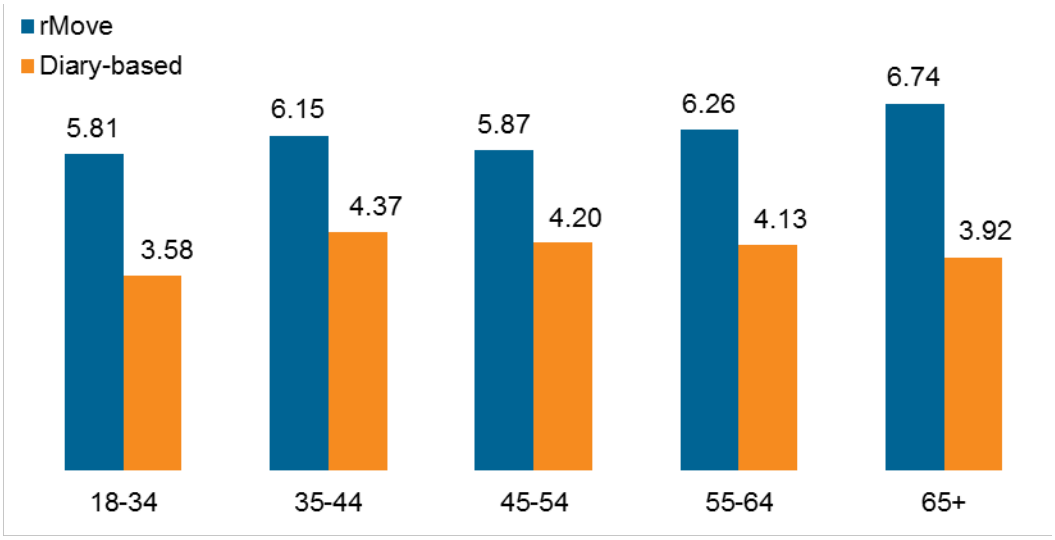
FIGURE 13: DISTRIBUTION OF SAMPLE BY PERSON-TRIPS/DAY



At the other end of the chart in Figure 13, we see that only about 5% of travel days in the diary-based data contain 10 or more trips, compared to much higher rates for the rMove travel days. This indicates that the increased trips rates for the smartphone method are also due to capturing more trips during busy travel days, which respondents may overlook or find too burdensome to report using the diary recall method.

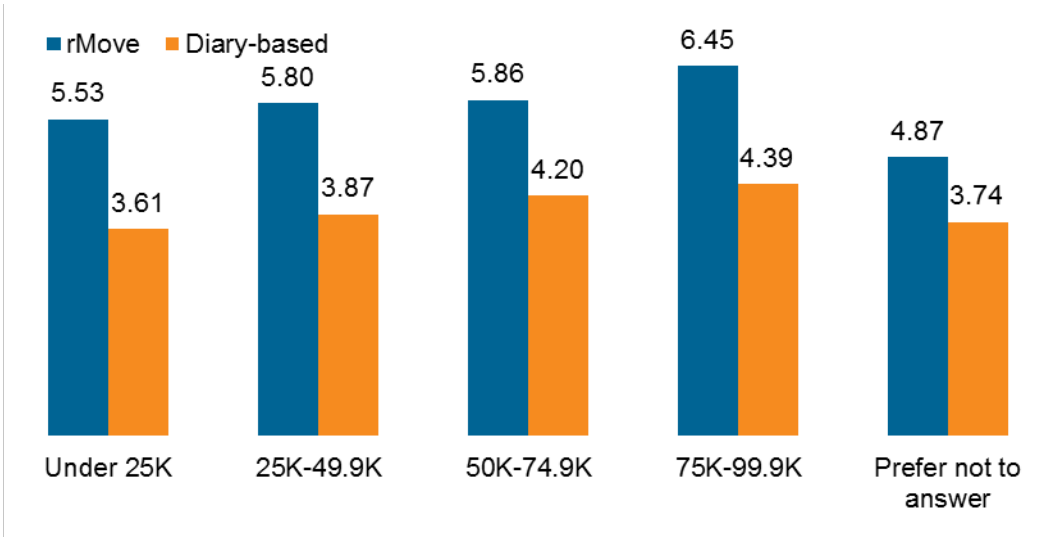
Another possible reason for higher trip rates with smartphone-based methods is a change in how self-selection bias may affect the data. With diary-based surveys, it has been suspected that even after accounting for demographic differences, those who are most busy and travel the most may be somewhat less likely to complete diary-based surveys due to respondent burden. There is at least some evidence that this type of self-selection bias is less pronounced for smartphone-based data collection, because of less perceived burden and/or the technological aspect being more appealing to certain types of people. For example, when analyzing the diary-based data across different age groups, we find that the 18 to 34 age group reports markedly fewer trips per day on average than other age groups—even the 65+ age group (Figure 14). When analyzing the smartphone-based data, however, this age difference is reduced, with no clear trend across the age groups from 18 to 65+years old. This finding suggests that: a) the younger age groups are less motivated when filling in diary-based surveys, but are more (ore equally) conscientious when using their phones; and/or b) the subset of younger people who are willing to complete smartphone-based surveys tend to travel more, on average, than the subset of younger people willing to complete diary-based surveys.

FIGURE 14: AVERAGE TRIPS PER RESPONDENT-DAY BY AGE GROUP



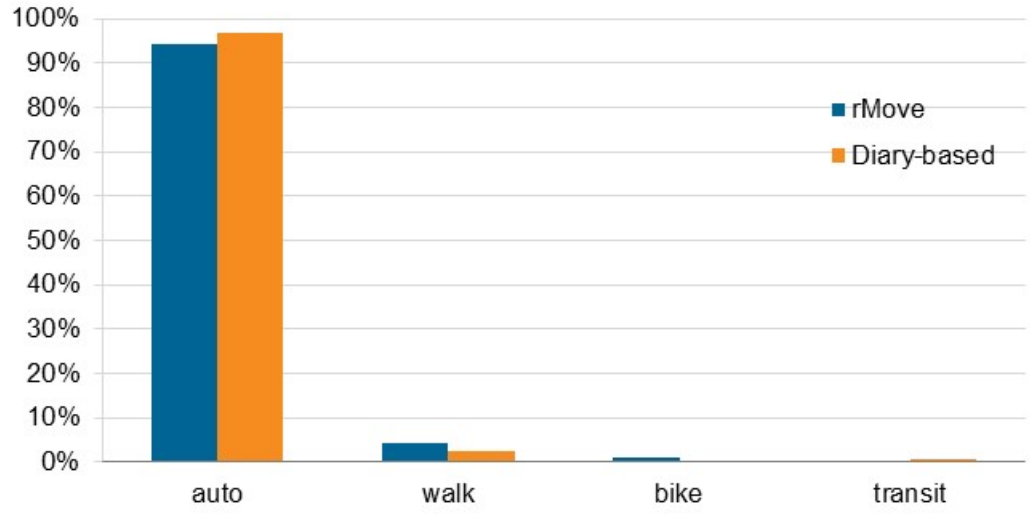
It is also interesting to look at trends in trips/day by household income level. In Figure 15, reported trip rates are similar across the different income groups for both the smartphone- and diary-based methods. The one exception is the higher-income households earning $75,000 or more, which reported a similar trip rate as other income groups in the diary-based study but have a higher relative trip rate in rMove. This provides some evidence in support of the supposition that the smartphone method may be more successful at capturing busier, higher-income households.

FIGURE 15: AVERAGE TRIPS PER RESPONDENT-DAY BY INCOME GROUP



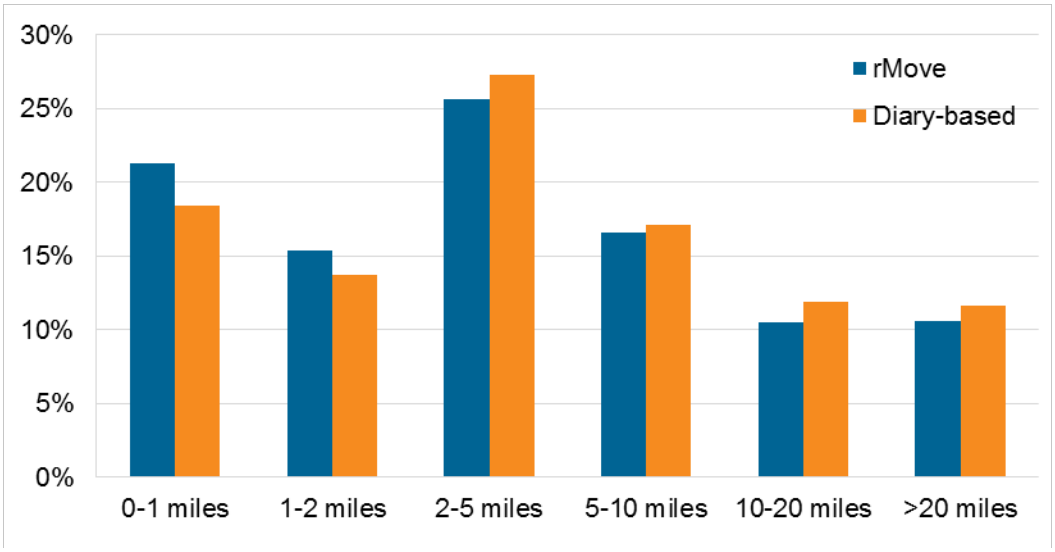
It is also interesting to compare the distributions of the trip characteristics for the two survey methods. Figure 16 shows that the percentage of trips by each mode is very similar for the two methods, with a slight increase in the percentage of trips that are by walk and bike, and a slight decrease in the percent by auto.

FIGURE 16: PERCENTAGE OF TRIPS BY MODE



When comparing the trip distance distribution (Figure 17), the two methods are again similar, but with the smartphone method providing a somewhat larger fraction of trips under one mile. (For rMove, the distance is based on the distance between trace points along the trip; for rSurvey™, it is based on the Google API road distance between the trip endpoints.)

FIGURE 17: PERCENTAGE OF TRIPS BY ONE-WAY DISTANCE



When comparing trips by destination purpose, the percentage of trips returning to home and trips for shopping purposes is lower for the smartphone-based method, while the percentage of work trips, meal/restaurant trips, and drop-off/pick-up trips is higher. As mentioned above, this may be related to the fact that the 2014 data cannot be isolated to just the smartphone owning households, while the 2015 data likely has fewer retired households.

FIGURE 18: PERCENTAGE OF TRIPS BY DESTINATION PURPOSE

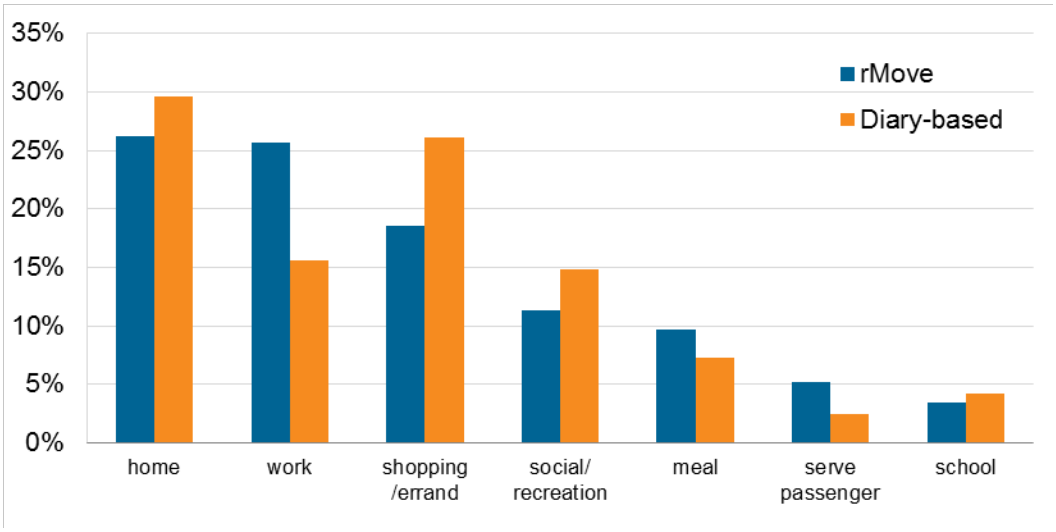
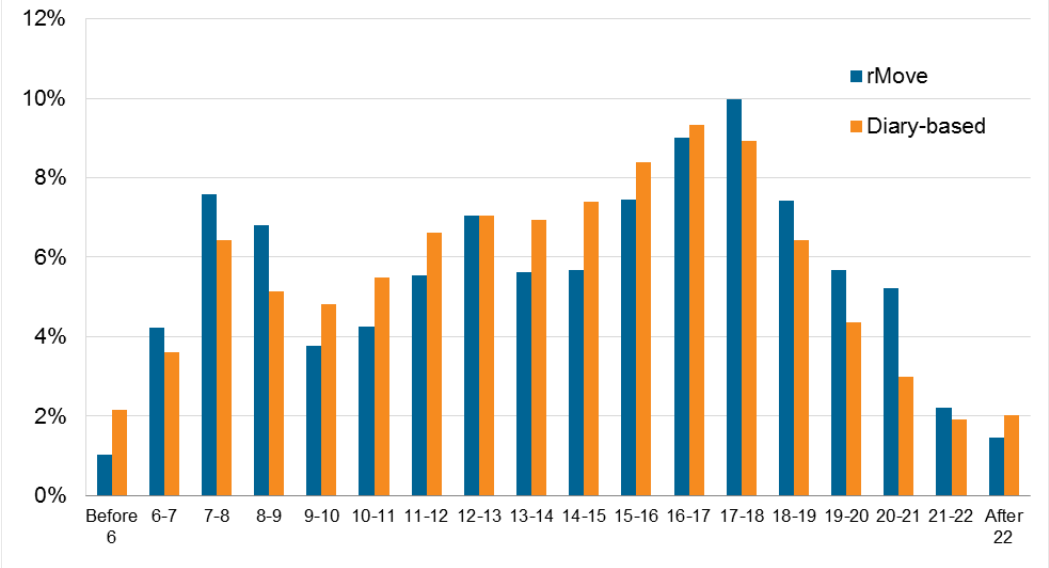


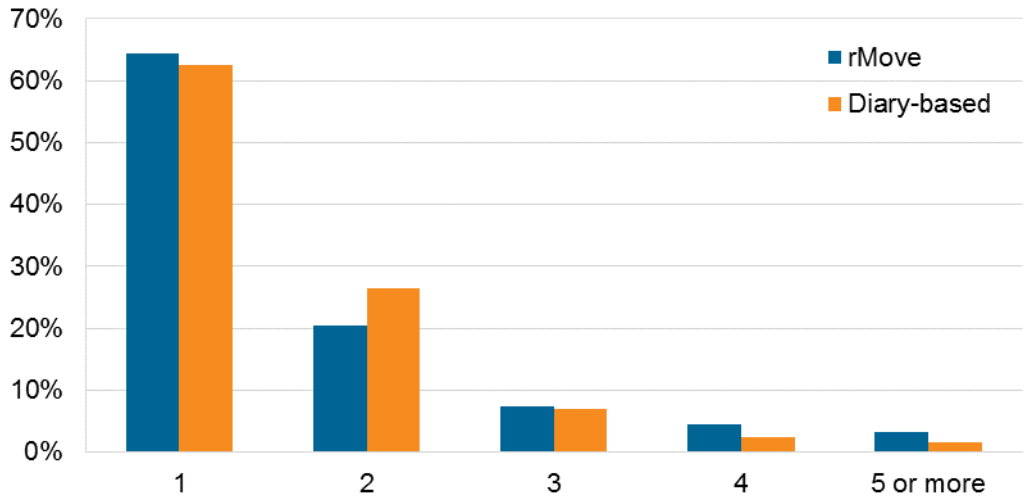
Figure 19 similarly shows a greater percentage of trips that start during the morning peak and fewer trips that occur during the off-peak hours. This is again likely related to the differences between the 2014 and 2015 sample as mentioned above.

FIGURE 19: PERCENTAGE OF TRIPS BY TRIP START TIME



Finally, Figure 20 details the percentage of trips by travel party size. The percentage of trips where the person traveled alone is 60-65% with both methods, and there are no substantial differences across the other groups.

FIGURE 20: PERCENTAGE OF TRIPS BY TRAVEL GROUP SIZE (NUMBER OF PERSONS)



Overall, the trip characteristics are surprisingly consistent across the two survey methods. rMove appears to capture about 25% more trips—with the greatest increase for the youngest age groups and highest income groups—but with no substantial shift in the types of trips (mode and travel party size) that are captured.

6.0 FOLLOW-UP SURVEY

6.1 | OVERVIEW

The project team issued a follow-up survey on May 18, 2015 to invited participants shortly after their travel period ended. The follow-up survey intended to obtain feedback on user experience with rMove, as well as to understand the reasons why some invited participants did not recruit or download rMove. All questions in the follow-up survey were optional, and no additional incentive was offered for participation. The follow-up survey final response was as follows:

- 105 respondents who had downloaded rMove
- 20 people who were invited to download rMove but did not download
- 66 people who were invited to the recruit survey but did not recruit

All questions in the follow-up survey were optional, and no additional incentive was offered for participation. Participants who downloaded rMove were asked about their use habits, experience, and satisfaction with rMove. Survey questions asked of these participants included questions about when the user answered surveys, ranking questions on user experience, experience among household members, comparisons to the 2014 study, and open-ended questions about rMove's features.

The survey was closed to response on June 2, 2015. Table 8 shows the response rate by respondent type.

TABLE 8: FOLLOW-UP SURVEY RESPONSE RATE

RESPONDENT TYPE	COMPLETED	INVITED	RESPONSE RATE
Downloaded rMove	105	295	35.6%
Did not download rMove	20	183	10.9%
Did not recruit	66	1,026	6.4%
Total	125	1,504	12.7%

6.2 | FOLLOW-UP SURVEY RESULTS

COMPARISON TO 2014

When comparing the experience of using rMove in 2015 to the online/phone-based survey experience in 2014, respondents generally favored the experience of participating via rMove. Eighty-seven percent (87%) of respondents agreed that participating in 2015 was easy, compared to 66% of respondents who agreed that participating in 2014 was easy. Similarly, 66% agreed that participating in 2015 was more fun than in 2014. While a slight majority of respondents (52%) agreed that they spent less time participating in 2015 than in 2014, 23% disagreed that they spent less time, which was the highest overall disagreement in any category. However, this is likely partially attributed to the fact that 2015 encompassed a seven-day travel period, compared to a one-day travel period in 2014.

TABLE 9: PARTICIPANT COMPARISON BETWEEN 2014 AND 2015

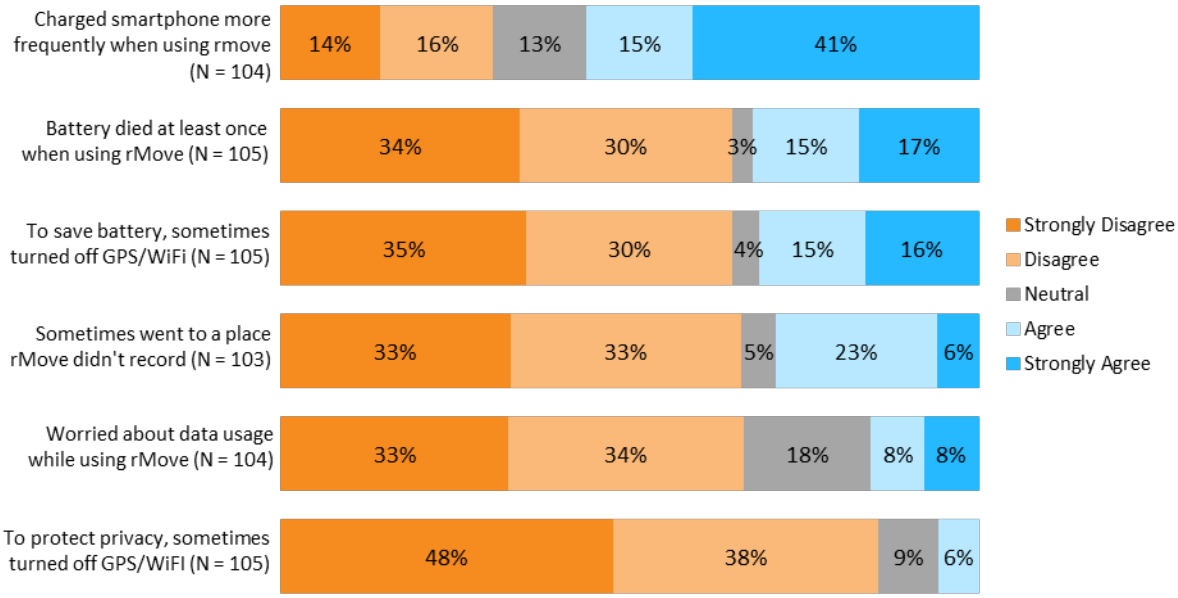
PARTICIPANT RESPONSES	STRONGLY DISAGREE	DISAGREE	NEUTRAL	AGREE	STRONGLY AGREE
Participating was easy in 2014	0%	13.3%	21.0%	42.9%	22.9%
Participating was easy in 2015	4%	3%	6.7%	30.5%	56.2%
Spent less time in 2015 participating than 2014	7%	16%	25.0%	20.2%	31.7%
More fun to participate in 2015 compared to 2014	3%	5	26.0%	27.9%	38.5%

USER EXPERIENCE

The follow-up survey asked a set of agree/disagree questions about various aspects of user experience. Battery-related issues were the most often agreed or strongly agreed with statements – just over half (56%) of participants agreed that they charged their smartphone more frequently when using rMove. Close to a third (31%) agreed that they occasionally turned off GPS or Wi-Fi to save battery over the course of the seven days. However, only a small percentage (6%) agreed that they

turned off GPS or Wi-Fi to protect their privacy over the seven days, which could indicate a lower level of concern regarding location privacy.

FIGURE 21: AGREEMENT/DISAGREEMENT WITH USER EXPERIENCE STATEMENTS



Results of ease of use and user experience questions were compared between age groups (under 45 vs. 45 and older) and smartphone type (Android™ vs. iOS™). However, few significant correlations were discovered. The lack of significant results is likely due to the small overall sample size and high degrees of freedom in the agree/disagree rating questions.

Battery depletion was recounted most frequently in the open-ended questions, when participants responded to "what can be improved" (20% of the 91 people who answered the question). Spurious trips were another issue commonly cited (24%). Ease of use was the most common "best feature" response (37% of 98 people who answered), as well as accuracy of trips captured (17%).

The follow-up survey also asked participants when they answered trip and daily summary surveys, in "select all that apply" questions. The majority of respondents (62%) said that they answered trip surveys right after they appeared in the app, and 60% of respondents said they answered several surveys at once. A quarter of respondents said they answered trip surveys when waiting in line or during other "down times," and 21% reported answering trip surveys all at once at the end of the day. Only one respondent (1%) said they answered trip surveys after several days. Responses to this question match the trip completion vs. survey completion trends observed in the data. With regard to daily summary surveys, the vast majority (98%) reported answering these surveys in the morning on the following day when they saw the survey in the app.

REASONS FOR NONPARTICIPATION

The follow-up survey also asked participants when they answered trip and daily summary surveys, in "select all that apply" questions. The majority of respondents (62%) said that they answered trip surveys right after they appeared in the app, and 60% of respondents said they answered several

surveys at once. A quarter of respondents said they answered trip surveys when waiting in line or during other "down times," and 21% reported answering trip surveys all at once at the end of the day. Only one respondent (1%) said they answered trip surveys after several days. Responses to this question match the trip completion vs. survey completion trends observed in the data. With regard to daily summary surveys, the vast majority (98%) reported answering these surveys in the morning on the following day when they saw the survey in the app.

TABLE 10: REASONS RESPONDENTS WHO DID NOT RECRUIT OR DID NOT DOWNLOAD rMOVE CHOSE NOT TO PARTICIPATE

REASON(S) DID NOT PARTICIPATE	COUNT	PERCENT
Other reason	32	37.2%
Does not own smartphone	26	30.2%
Did not see e-mails	13	15.1%
Privacy concerns	12	14.0%
Too busy	8	9.3%
Doesn't use smartphone frequently	7	8.1%
Tried but had problems	7	8.1%
Battery concerns	3	3.5%
Did not understand how to participate	1	1.2%
Total	86	100%

7.0 POTENTIAL FUTURE CONSIDERATIONS

Below are initial findings and suggestions for how these smartphone-based studies can continue to become scalable and effective here in the U.S.

7.1 | ADMINISTRATIVE

It is always useful to remind that even if the transportation industry had perfect technology and perfect awareness of modeling needs, there still remains the challenge of getting households to successfully participate in these studies. That challenge is largely administrative. Below are a few administrative findings and recommendations for future projects:

Findings

- The inherent and arguably largest challenge of convincing invited participants to actively engage with the study remains regardless of technology. Similar to other RSG travel survey work, once engaged, the retention rate of households is very high (at about 90%).

- Borrowing and adapting methods from traditional surveys (such as frequency and means of communication) is suitable and successful. Regardless of method of survey, participants need well-timed reminders to encourage study completion.
- The more advanced the technology, the more useful to have user-support plans and processes in place. Many users are quite knowledgeable, but some smartphone users require help in successfully downloading and using smartphone apps.
- Continuing to offer multiple methods for participants to communicate is valuable – some will continue to e-mail, others call, and still some send feedback or questions via rMove itself.

Suggestions for Future:

- Ensuring that smartphone-based travel surveys offer additional flexibilities that traditional methods offer, but scope and budget did not allow for on this project. Most specifically that would be conducting a longer overall data collection such as months instead of weeks. Other flexibilities would be offering households the ability to change travel dates if they were out of town during their assigned travel period.
- Further refining print and online study materials for clarity for participants. A common language of how to speak about smartphone apps is still somewhat nascent and RSG believes some definitions may help users. (e.g. "What does having the app 'on' mean?") Similarly, continuing to clarify understanding of data privacy and data security will be useful in study materials.
- Determining a process, both efficient and cost-effective, for distributing smartphones to households where all or some adults do not have them. These households are known to be more likely low-income and older. An alternative is simply offering the traditional approach (phone or web) to these households. Regardless, they all have different demographics and travel behavior and it will be essential to include them in datasets/studies.

7.2 | SMARTPHONE APP (RMOVE) TECHNOLOGY

As with any technology that is fielded for the first time, there are clear findings and possible improvements.

Findings

- A smartphone-based travel study is indeed viable and in fact is a far more appealing participation method for multiple demographic groups. As an example, just over half of participants reported the 2015 study requiring less time than 2014, even though they participated for a week instead of a day.
- The perception of convenience and lower burden exists with two-thirds of participants reporting it to be more fun to participate in 2015 (than in 2014).
- Moreover, it is also viable for these studies to collect longer periods of data with almost 90% of participants participating for all seven days.

Suggestions for Future:

- Suggestions for improving rMove (or any smartphone-based travel survey app) should focus first and foremost on continuing to improve data completeness. Secondary goals should then include further efforts to reduce burden and features to provide data "back" to users. In this

vein, below are the top suggestion features to add to the app. Each of these features will improve data completeness (as well as lower burden).

  - Allowing users to "split" and "merge" trips within rMove.
  - Allowing users to add trips in rMove when the app misses trips.
  - Allowing users to add trips in rMove that nonparticipants (e.g. children) make that rMove did not capture (in capturing another family member's travel day).

- The next highest priority for improvement of overall data completeness will continue to be honing the apps accuracy along several dimensions:

  - Minimal spurious trips shown to the user and included in a dataset
  - Reducing the "cold start" challenge so that the route/trace at the beginning of the trip becomes more accurate
  - Tuning alerts provided to respondents so that they don't download late or uninstall early during the travel period
  - Adding a "send data" feature so that users have some ability to do this.
  - Additionally, research options for how to know if a user uninstalls the app from their phone (drop-outs) vs appears to have sensors off (could still be an active participant).
  - Improving meta-data provided back to the survey such that RSG can even better provide user support. An example is providing version number of the app back to the server as this would be useful for long(er) data collection periods. A second example could be capturing the time required to complete each trip survey.

- Longer-term it will be essential to further extend "trip matching" intelligence within the app along a number of dimensions. The importance of this is that as the novelty of smartphone-based travel surveys wears off, it will need to be ever easier for users to participate. Secondly, this can reduce unintentional user error (e.g. instances of accidentally selecting the wrong answer choice on the smartphone screen), therefore further improving data quality.

7.3 | IMPLICATIONS FOR TRAVEL DEMAND MODELING

The main implications for travel demand modeling include a number of issues:

- Compared to more-traditional methods, smartphone-based surveys can provide a more complete "inventory" of household trip-making, with particular benefits for shorter trips such as walk and bike trips, including "loop trips" for exercise or recreation.
- It appears possible to complete smartphone-based surveys for up to seven or more days per respondent with no apparent drop-off in survey participation or completion rates. Furthermore, all travel days have full trip details and can be used in modeling. This not only provides more useful data per respondent, but can enable new types of models, such as the allocation and substitution of activities across days of the week.
- Initial evidence suggests that smartphone-based surveys are less prone to some of the types of nonresponse bias and self-selection bias that have been prevalent in past diary-based travel surveys—particularly the biases toward older households and less "active" respondents.
- Smartphone-based location and time-of-day data are inherently more accurate than the data reported by respondents. This is even more true for smartphones, which people tend to carry

with them almost everywhere, than it is for the GPS devices used in previous travel surveys, which people tend to forget or leave in their vehicles.

- Smartphone-based surveys also provide trace data, from which respondents' travel routes and speed profiles can be derived. (Here, there is a careful tradeoff between accuracy of the data and the amount of drain on the phone battery, which should become less of an issue in the future as smartphone sensors continue to improve.)

In 2015, about 70% of adults in the United States own smartphones, with the percentage of smartphone users increasing rapidly. However, the approximate 30% of adults who do not own smartphones is significant, and our experience has shown that some of them are not willing or able to complete surveys by smartphone even if one is provided to them for free.

Given this impediment, the foreseeable future we may need to rely on mixed methods, with some respondents providing data via smartphone and others using more-traditional diary-based methods. Using mixed methods need not adversely impact modeling, however, as long as the survey is designed so that the different methods provide the same data items, meaning that the data can be merged and used jointly in analysis. When that is the case, one can estimate "bias parameters" on the nonsmartphone data cases in order to identify and adjust for any method-specific differences. In a sense, this is the reverse of the way GPS data has been used in the past for trip-rate correction, and is much more powerful in this case because both types of data can be used jointly in modeling. Thus, bias parameters can be estimated not only for trip or tour generation rates, but also for other variables such as mode choice constants and time-of-day choice constants.

7.4 | POTENTIAL FUTURE ADDITIONAL ANALYSES

As with any project of this nature, it is difficult to accomplish all potential or desired analyses. A few remain and are provided below so that these research questions can be tackled on future projects. Additionally, if so, then RSG can provide an update back to MCCOG.

- Conduct a more thorough analysis of different reporting patterns by phone type (e.g. do Android users make more trips than Apple users and is that due to demographic differences or technical differences in the phone or app?)
- Conduct additional analysis of "matched trips" (e.g. What are the characteristics of matched trips that users did not change vs did change? What further logic or intelligence can be gleaned for future software improvements?
- Evaluate the capture of multimodal trips by rMove – both those reported by users and those not reported by users (where only one mode was reported).
- Conduct additional analyses comparing the 2014 and 2015 datasets.

Additionally, RSG is currently working on an evaluation so that additional guidance can be provided to agencies on several fronts:

- What are the expected future costs of conducting smartphone-based travel surveys? And how quickly can those costs continue to decrease as technology stabilizes? (This is similar to the question asked about online surveys about 15 years ago.)

- What is the recommended mix of smartphone-based sample and traditional-participation (e.g. online, telephone, paper) sample to balance costs with data quality? And what implications are there for data merging in the near-term where projects have a mix of sample types?

7.5 | CONCLUSION

This report details the design, approach, and results of a smartphone-based seven-day household travel diary conducted in Indiana for MCCOG and the FHWA Office of Planning and Office of Transportation Policy Studies. While these projects are increasingly conducted internationally, very few have been conducted in the U.S. A primary goal of the research project was to fully test the viability of longer periods of data collection using a smartphone-based GPS app to conduct a household travel diary over seven days. A second primary goal of the project was to employ as many innovative technological features as possible in the smartphone app's passive data collection and active survey questions in order to further combat respondent burden and encourage sustained active participation. These project goals acknowledge the four trends of smartphone sensor technology rapid improvements, smartphone ownership rate rapid increases, continued decreases in response rates to traditional survey methods (paper, telephone, and web) which leads to higher project costs, and the transportation modeling community's growing desire for ever more detailed, longitudinal data.

Participation in a seven-day smartphone-based HTS proved successful on numerous fronts. Almost 90% of participants were active participants answering all surveys over the full seven-day period and almost three-quarters (71%) of trip surveys were answered within five hours of the trip occurring. Indeed, 17% of trip surveys were completed within 10 minutes of the survey notification appearing to the participant. As part of the follow-up survey, 87% rated their 2015 survey experience as easy, while 66% rated their 2015 survey experience as more fun than their 2014 survey experience. Indeed, 52% rated their 2015 survey experience as requiring less time than in 2014. This despite the fact that only a one-day travel diary was required in 2014, while the 2015 travel diary was for a seven-day period. These results point to at least a perception of reduced burden among participants and to a potential improved accuracy of responses, given the small amount of time that elapsed between travel and survey completion.

As with any research project, it is essential to assess potential improvements. Areas of focus for future improvements include firstly focusing on the quality and completeness of data by further examining options for limiting battery drain, and providing an improved means to report any missed trips (e.g. forgetting to take the smartphone on a specific trip). Ease of use will also remain a priority for ensuring actively engaged participants across regions and demographics, as well as for the researchers, modelers, and planners interested in utilizing the resulting datasets.

For several years now, the travel survey community has been primed for a period of change and improvement. We remain optimistic that these approaches will lead to superior data for modeling, a noticeable improvement in participant burden, ultimately lower project costs (due to skyrocketing smartphone ownership rates), and improved understandings of travel behavior.

8.0 APPENDICES

The appendices were provided to MCCOG in July 2015 and can be re-provided upon request.

8.1 | INVITATION AND REMINDER E-MAILS

8.2 | RECRUIT SURVEY SCREENSHOTS

8.3 | RMOVE INSTRUCTIONS

8.4 | RMOVE SCREENSHOTS

8.5 | FOLLOW-UP SURVEY SCREENSHOTS

8.6 | DATASETS AND TABULATIONS

RECRUIT SURVEY – HOUSEHOLD DATASET

RECRUIT SURVEY – PERSON DATASET

RECRUIT SURVEY – VEHICLE DATASET

RECRUIT SURVEY – TABULATIONS

FOLLOW-UP SURVEY – HOUSEHOLD DATASET

FOLLOW-UP SURVEY – TABULATIONS

FOLLOW-UP SURVEY – OPEN-ENDED COMMENTS