The Future Mobility Survey: Experiences in developing a smartphone-based travel survey in Singapore

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Word count: 6706 + 5*250=7956

Abstract:

The Future Mobility Survey (FMS) is a smartphone-based prompted-recall travel survey that aims to support data collection initiatives for transport modelling purposes. This paper details the considerations that have gone into its development, including the smartphone apps for iPhone and Android platforms, the online activity diary and user interface, and the background intelligence for processing collected data into activity locations and travel traces. We discuss the various trade-offs regarding user comprehension, resource use, and participant burden, including findings from usability tests and a pilot study. We find that close attention should be paid to the simplicity of the user interaction, determinations of activity locations (such as the positive/false negative trade-off in their automatic classification), and the clarity of interactions in the activity diary. The FMS system design and implementation provides pragmatic, useful insights into the development of similar platforms and approaches for travel/activity surveys.

Introduction

Technological advances have had numerous impacts in the realm of travel surveys. From the use of GPS-enabled devices to better track trips, travel times, and modes, to the move from paper diaries to online reporting, the growing range of available tools have improved the methods used to collect traveler data, as well as the ways in which those data are used. These advances, however, also bring challenges to the practitioner, who must balance the potential to collect nearly unlimited amounts of data with the need to reduce participant burden and develop a system applicable in a variety of contexts and range of purposes (e.g., household or freight surveys). This paper describes on-going efforts to strike this balance in the context of the Future Mobility Survey (FMS), a smartphone-based travel survey currently being developed and deployed in Singapore as a subset of the nationwide Singaporean Household Interview Travel Survey (HITS), conducted every four to five years.

The rise in the availability of location-enabled devices has greatly expanded transportation data collection options. Whereas our decades-long experience with household travel surveys typically depended precariously on the vagaries of human memory, we can now track, in great temporal and spatial detail, agents' (human or not) movements and activities. While not infallible, and requiring a good deal of processing, GPS, GSM (Global System for Mobile communications), Wi-Fi and accelerometer data such as those collected by smartphones can lead to detailed and precise data needed for emerging agent- and activity-based behavioral models. Developments in this field (e.g., *1, 2, 3, 4, 5*) suggest that location-enabled technologies can reduce the number of erroneous "no travel" days and missed trips; improve accuracy of reported trip times, locations and paths; and reduce respondent burden.

These and other benefits have resulted in a move towards the use of dedicated GPS loggers and, to a lesser extent, smartphones for travel surveys. This paper reports on an approach to develop a comprehensive smartphone-based transport survey that may function as a platform for conducting a variety of additional surveys and survey types. First, we describe the state of the practice with GPS- and other location-enabled travel surveys. Next, we detail the structure and components of the FMS, including a short discussion of the initial pilot study undertaken to test the system. We conclude with "lessons learned" from these initial efforts. We aim to provide useful information for others interested in more fully integrating location-sensing technologies into the realm of transportation surveys.

Background

While smartphone-based travel surveys are in their infancy, GPS-based surveys have been widely implemented worldwide, beginning with a proof-of-concept study conducted for the U.S. Federal Highway Administration in Lexington, Kentucky (USA) in 1996, and expanding to projects in Australia, the Netherlands, Canada, and Israel, among others (*6, 3, 7, 8, 9*). However, although GPS can record accurate time and geographic information of travel, participants must still provide detailed attributes such as trip purpose and mode. To collect information that cannot be derived from GPS data alone, various prompted recall methods may be used, including paper-based (*10*), mobile phone-based (*11*), and web-based (*12, 13, 1, 14, 15, 7, 16, 17*). The type of recall method depends in part upon the type of survey being conducted, as well as the demographics of the population of interest (access to a computer, language skills, etc.). For example, Stopher, *et al.* (2007), in a Sydney (Australia) study, provided GPS survey respondents with the option to complete their prompted recall section via telephone, Internet, face-to-face interview, or mail; phone and mail surveys had the greatest percentage of completions, internet the fewest. Such findings suggest that prompted recall methods incorporating some interaction between the surveyor and the survey participant will be most successful; however, such interaction may increase both the survey implementation cost and completion burden.

While largely successful when used as a supplement to household travel surveys, GPS suffers from some limitations. Financially, agencies conducting travel surveys must purchase and distribute GPS collection devices. While these devices' costs have dropped considerably since first introduced, they still represent a significant investment. Units may be reused over time, but the potential for loss, damage, or theft may make agencies wary of investing in them. Smartphones may help overcome this hindrance as they belong to the survey subject, reducing the agency's investment burden. Functionally, GPS loggers pose a potential recollection problem, whereby participants forget to carry the GPS logger with them for the duration of the travel survey. Here, smartphones provide a clear benefit, with users accustomed to carrying their phones with them constantly, decreasing the likelihood of missing trips.

Smartphones are increasingly ubiquitous and versatile loggers. Besides GPS, they generally include a variety of sensing technologies such as accelerometer, WiFi, and GMS, the combination of which may provide more detailed information on traveler behavior, as well as data when GPS is inadequate for determining traveler location. For example, the University of Minnesota's UbiActive application uses data captured from 3-dimensional accelerometer, GPS and 3–dimensional magnetic sensors to determine such inputs as movement time, speed, and orientation in order to calculate physical activity duration and intensity (*18*). Users are prompted to provide information regarding their well-being, or satisfaction with their travel, at the conclusion of each trip. In addition, the app provides users with information regarding their physical activity and calories burned. Smartphone-based surveys have been proposed or explored by the California Department of Transportation (Caltrans) and District IV of the Florida Department of Transportation, highlighting the expectations for these technologies to supplement or enhance traditional travel survey methods. In the following section we describe efforts to develop a pragmatic "base" survey that may be used both as a stand-alone travel survey, as well as a platform for the development of additional surveys as more sensors and sensor applications are developed.

The Future Mobility Survey (FMS)

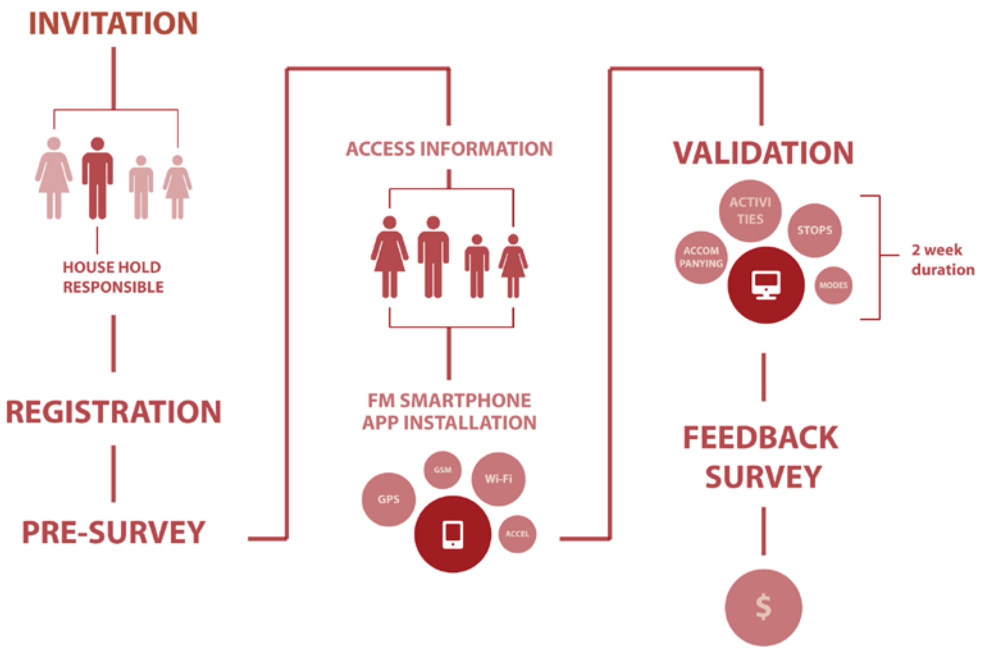
The FMS collects user input at four stages:

1. Registration: The household responsible (HR) provides basic household information, including age range, gender, education level, relationships among members, and contact emails for those participating in subsequent stages;
2. Pre-survey: The HR provides more detailed information about the household, including socio-economic information, vehicle ownership and others;
3. Activity diary: Participants visit the FMS website to validate activity and mode information recorded and detected from use of the FMS app (described below);
4. Exit survey: Participants provide feedback on the survey experience and additional household and preference information.

These four stages are supported by FMS's technological components (namely, the app, server, and web interface), described below.

Workflow and technological infrastructure

The FMS global interaction workflow is presented in Figure 1.



Legend:  - Part to be filled by every member of the household.  - Part to be filled only by the household responsible

Figure 1: FMS workflow

From the user's point of view, participation takes place as follows:

- Surveyor invites users to participate.
- User accepts invitation in the name of his/her household, becomes the *household responsible* (HR), and registers in the online registration form.
- The HR receives an email with login activation, directing him/her to complete the pre-survey. In parallel, every other household member who will participate will also receive access instructions via email.
- Household participants download, install, and begin running the FMS smartphone app, available both for both iOS- (i.e., iPhone) and Android-based phones. Each participant signs into the FMS website periodically to validate his or her daily activities and travels.
- Over course of survey, participants are asked, on two randomly selected days, additional questions about satisfaction with travel and travel plans for the day.
- Once fulfilling the participation terms (currently set at data collection for two weeks with activity validation completed for at least five of those days), participant completes a follow-up survey providing information on experience with the app, the activity diary, and the overall survey.
- After completing the follow-up survey, participant receives a SG$30 (US$25) incentive. Participant can end participation or continue collecting data as s/he wishes.

We designed the process to be simple for the user, providing data and information in a clear, concise, and intuitive way. In the background, however, lies a far more complex process, following the general architecture shown in Figure 2. The *smartphone app* uploads data to the *server*, where several close to real-time algorithms are used to prepare the data for the *web interface*, with which the user mostly interacts.

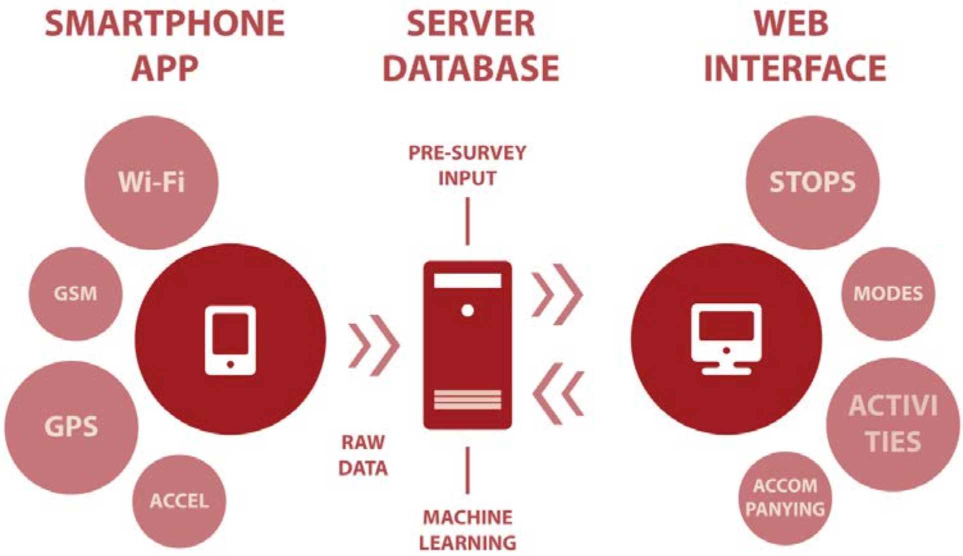


Figure 2: Survey architecture

The translation of raw data into traces and activities, to minimize the user's interaction burden, requires the application of *background intelligence*. Raw data, collected through the smartphone's sensors and uploaded to the server, are used to locate the smartphone in space with varying degrees of accuracy, and processed to help determine the user's activity locations and transportation modes between them. Pre-survey inputs (e.g. ownership of cars, bikes, motorcycles, etc.), past validations, frequently visited places, and Points of Interest (POIs) tables create a contextual knowledge base to improve detection accuracy and help infer activities. Machine learning classifiers gradually learn as the user interacts with the interface; for example, the user's home and work locations are quickly "learned," based on postal code and frequent occurrence, and pre-filled for the user on the web interface.

While some characteristics make relevant dimensions fairly simple to ascertain (for example, walking speeds make the "walk" mode somewhat easy to identify), others pose more difficult challenges based on available sensor information. Differentiating between private cars and taxis, for example, can be problematic as can be identifying the mode change from riding a bus to walking to the final destination, since the sensed transition is fairly smooth. To overcome such difficulties, we opted for using the prompted recall survey together with the background intelligence. Using both automated intelligence and user-provided data enables the FMS to gather accurate and detailed data, with limited time required for user interaction.

Finally, we designed the overall user interface to satisfy three objectives: meeting modeling priorities, satisfying a broad spectrum of user types, and minimizing technological complexity. The FMS is part of a project to develop next-generation activity-based models; thus, we prioritized accurate data collection for determining activities, modes, locations and routes, in this order. For example, the interface design reflects that, for us, obtaining the precise route from A to B is less important than accurately identifying the activities performed at and mode(s) taken to B, since ground truth for the latter is harder to capture from sensing data. Route identification can be performed via post-processing by, for example, using probabilistic map-matching (*5*) and filling gaps with route planning algorithms (e.g. Google maps API). Regarding users, since the FMS is expected to function independently (i.e., with little dependence on surveyors for assistance), we aimed to develop a smartphone application and website for persons who are not especially familiar with these technologies, and/or are poor map-readers and/or dislike interacting with traditional online surveys while happily interacting with maps and icons.

FMS' technological complexity challenged the interface design. For example, the interaction between the smartphone and the web interface needs to be as seamless as possible while allowing the user to assimilate the functional link between the two (e.g., without running the app, data won't be in the website; with GPS turned off, the data will be poorer). Furthermore, the interface must compensate for limitations such as low data quality, enabling, for example, the user to easily add/merge/delete locations or correct a wrong mode inference.

The following sections generally describe our approaches to meeting the above objectives and then provide more specific descriptions of the on-going pilot study and forthcoming Singapore Land Transport Authority (LTA) Household Interview Travel Survey (HITS).

Pre-survey

As noted above, the FMS will be tested as a subset of Singapore's 2012 HITS, with plans for 1,000 smartphone participants (out of roughly 30,000 regular participants). Questions included in the FMS intend to reflect and be compatible with HITS (which currently consists of a demographic survey and a one-day activity diary) for comparability and consistency of results. Converting the LTA's paper-based diary into an online format, however, raised a number of questions associated with participant cognitive burden, question ordering, and use of visuals.

Our interface design resulted in considerable differences in question ordering and flow between the paper and online versions. Properly calibrating behavioral models using data from both survey forms will require consistency checks between instruments to ensure that modified questions, differences in survey visualization (e.g., enhanced use of color images and more diversity in fonts and images in the online survey), and/or question ordering do not significantly impact responses or the likelihood of full engagement.

Comments from pilot participants and usability testers indicated that our pre-survey questionnaire, designed to mirror HITS, was regarded as a burdensome and lengthy process (usability tests reflected a general completion time of 15 to 20 minutes). As a result, questions necessary for the development of the background intelligence, such as household size, home and work addresses, and availability of vehicles, were retained in the pre-survey, while remaining questions were moved to the exit survey. In addition, we attempted to limit the perceived length of the pre-survey by using questions responsive to earlier answers (for example, only asking about details of the workplace if the user has indicated that he is employed).

We faced several additional specific concerns related to the use of online surveys, including:

- Mandatory versus optional question responses
- Limited question responses
- Question ordering
- Privacy and confidentiality

These four concerns are intertwined. For example, consider the ability in online surveys to make responses mandatory by disallowing the participant to continue to the next question without having provided an answer to the current question. In traditional paper-based surveys, participants may move through at their discretion, leaving blank any questions they prefer not to answer. The ability to make certain questions mandatory presents both an opportunity and a conundrum to the data user: with too many mandatory questions, the user may feel her privacy is being invaded and decline to continue with the survey; conversely, with too few mandatory questions, the participant may not provide enough information for the survey results to be usable. We balanced this by providing "prefer not to answer" response options, and presenting answer options for sensitive questions in general terms (for example, using categories for age and income instead of requesting specific answers). Additionally, following suggestions in (*19*) and others, we ordered the questions to introduce sensitive topics, such as income and ethnicity, once the participant has already become invested in the survey. Finally, approaches to the protection of privacy and confidentiality of answers provided in the pre-survey (and, indeed, across all portions of the survey) are documented thoroughly in the application's privacy policy, which outlines both technological and access control methods of privacy preservation, and specifically states limitations on how collected location data will be shared.

Smartphone applications

Another area of overall concern relates to the use of participant resources for purposes of the survey, specifically the phone's battery and the user's data plan. Battery drainage due to the use of location-sensing apps has been widely discussed in the literature (*20, 21, 22*). Unlike, for example, a GPS logger survey where a separate device is used, here we must ensure that the phone can gather participant data without impeding regular (often intensive) use of the phone. Towards this end, we have focused on the concept of "phased sampling," turning GPS off for long periods to conserve energy (as demonstrated in the "funf" open sensing network (*23*)). During sleeping periods, the app collects only GSM, Wifi and Accelerometer data, while in awake periods it also collects high frequency (1 Hz) GPS data. The approach helps to conserve battery life while maximizing the probability of capturing reasonably detailed information on activities of interest. We tested various phone sleep/wake duration patterns, including standard durations (i.e., 5 minutes sleeping, 10 minutes awake) and durations set by likely activities (i.e., longer sleeping times when participants are likely to be stationary in an office or at home). We use complementary techniques, namely using accelerometer and WiFi to signal trip start/end (i.e. force GPS fix) to avoid missing important details, yet, overall, we still face a trade-off between resource efficiency and data accuracy, with phased data collection inevitably reducing the data quality during GPS sleep time. Furthermore, our app provides the user with options regarding the method of data upload (continually, based on the mobile data plan and/or Wi-Fi, or opportunistically, based on Wi-Fi only) to give the user some degree of autonomy. Ultimately, we have attempted to ensure that a phone will last for a full day without recharging, while not overly compromising data accuracy. We have tested all of these methods in the pilot, and they remain under constant testing and refinement.

In developing the smartphone application itself, we have opted for a simple and non-intrusive interface, as shown in Figure 3. The primary interaction that the user has with the app is to sign in and sign out as necessary, though she may also choose both how to sync data to the server, and at what level of battery loss the app will log out automatically. While we have considered the possibilities for the user to complete the activity diary on the smartphone app and/or for the app to provide feedback to the user, we leave those possibilities for future evaluation, for two reasons. First, we are aiming to keep the application as unobtrusive as possible, running in the background, to minimize battery loss and bother to the user. Second, as our initial intention is to supplement, if not eventually replace, a traditional household travel survey, we must minimize the instrument's influence on the behavior of interest. Although interesting for other experimental designs, and certainly viable with modifications to our current approach, providing behavioral feedback to the participant would run counter to our specific purposes.

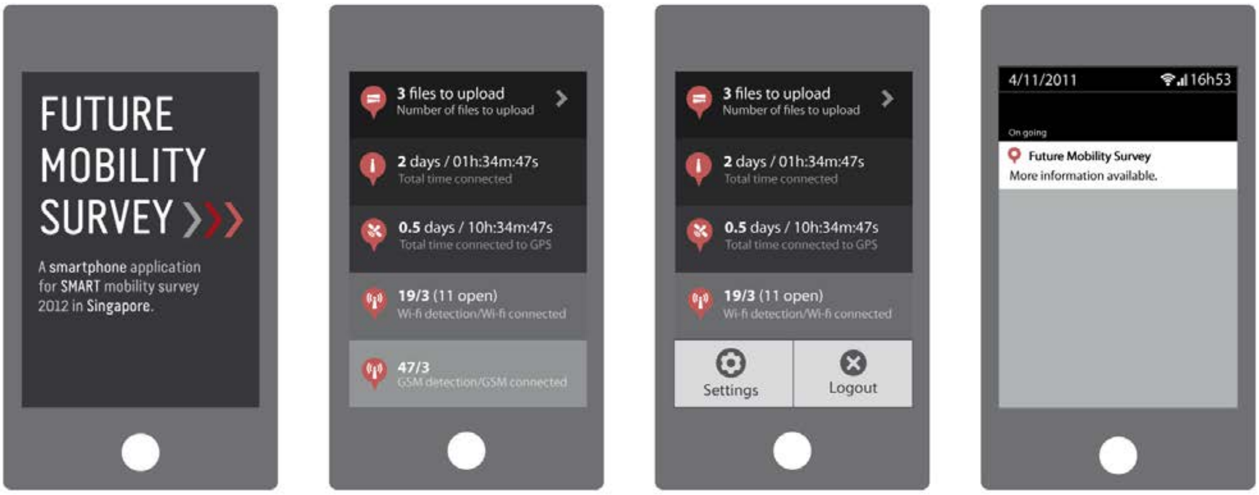


Figure 3: General application interface

Activity diary

Given the spatio-temporal resolution of the data collected and processed, we chose a web interface as the simplest option for immediately presenting these data clearly to users. In turn, this decision led to a number of additional considerations and concerns. As noted by MacKerron (p. 21, 2011): "Survey implementation matters… more on the web than in some other modes: an online instrument must compensate for the lack of trained interviewers to administer it. Web survey implementation affects accessibility, compatibility and consistency across respondents; it affects respondent motivation and experience; it creates context effects, and has implications for data security."

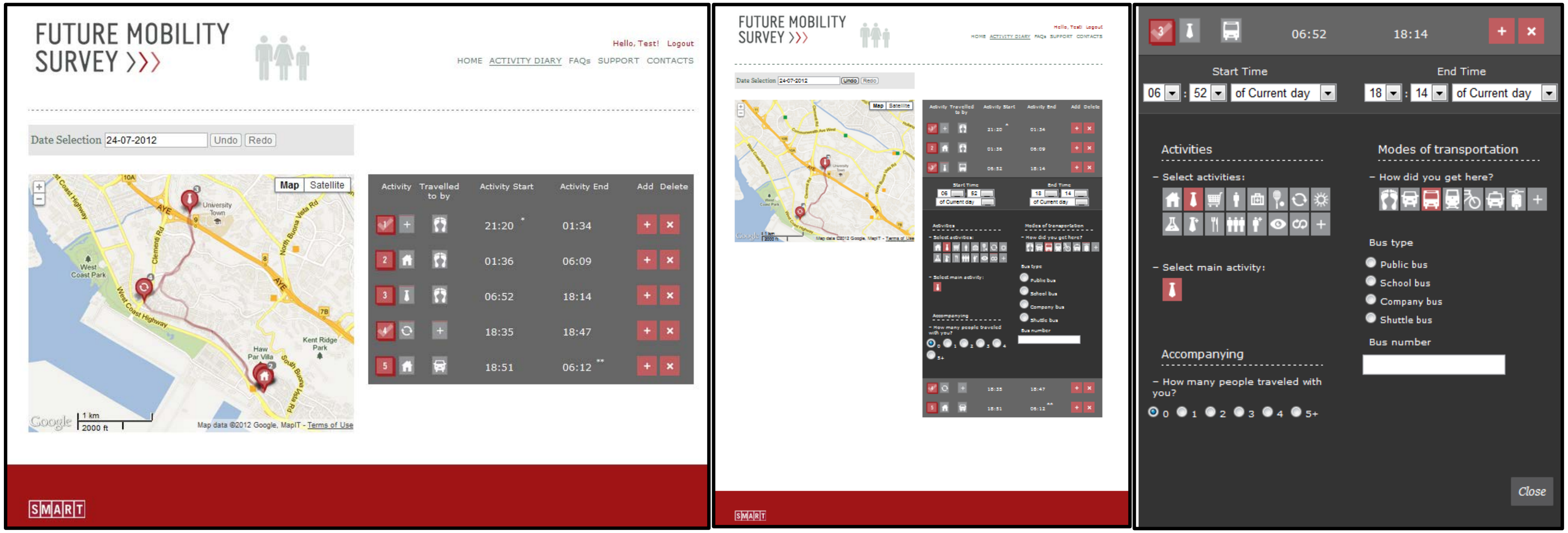


Figure 4: Web-based FMS Activity Diary Interface, including Full screen, Full screen with open location, and detail of open location (from left)

Aiming to provide adequate information without overwhelming the user, we designed the on-line interface to reflect the survey content and be consistent with the smartphone application – all in a way that makes the flow of the activity diary intuitive to the user with a minimum of interaction points shown on any one screen (Figure 4). Since the smartphone application and backend processing enables the generation of detailed maps of a day's travel and activity points, the interface employs such maps to jog the participant's memory and allows for editing as needed. By making mode- and activity-specific questions responsive to user choice, we attempt to minimize extraneous text shown on the screen, thus reducing the user perception of burden.

Two waves of usability tests, performed with five participants each, helped clarify these decisions. We attempted to perform the test at the person's home and on her personal computer when possible. Each test took 1-2 hours to perform, on average. A "think-aloud" protocol was used, in which participants shared their experiences and thought processes aloud as they performed a series of tasks. Key commentaries were registered, as was body language and/or the steps chosen by the user in her interaction with the system (*25*). Based partly on these usability tests, we made the following decisions regarding the activity diary:

- Match the map to user interactions with the diary (reflected in consistent numbering, icons, and highlighting when interacting);
- Maintain readability for users based on use of colors and a readable typeface;
- Minimize textual content while ensuring adequate direction;
- Clearly organize content to guide the user to perform needed tasks (for example, group all questions related to a particular activity on one screen to direct the user to respond to all questions about that task);
- Present questions clearly, with limited but sufficient options; and
- Provide adequate guidance in legends for activity and mode selection.

Feedback from usability testing led us to develop responses to frequently asked questions (FAQs) and a tutorial video.

Exit survey

Once the user has completed two weeks of data collection and has validated five days of activities, he is prompted to participate in the exit (or feedback) survey. This survey serves two functions: providing feedback on the user's experience with the overall survey (including registration, installation, and filling out the activity diary); and, distributing demographic and preference questions between segments of the survey to lessen the response burden at any given time. As noted above, early users (including from usability tests) considered the pre-survey too long, thus we shifted some questions, non-essential for deriving travel and mode intelligence, to the exit survey. This shift reduced perceived burden and provided space for additional questions to be asked. We expect feedback from this section to both assist with improving the overall survey experience as well as provide information comparable to the standard HITS instrument.

Pilot Implementation

In February 2012, implementation of the FMS pilot began. The pilot was primarily intended to test the user interface for both the website and app and the overall structure of the survey and collected data. Recruitment took place via social networking sites (such as Facebook and Twitter), networks within both the National University of Singapore (NUS) and Nanyang Technological University (NTU), posted flyers and personal contacts, resulting in a voluntary convenience sample. This recruitment approach did not allow for the calculation of such measures as coverage, sampling, or non-response error, as we could not determine how many persons had seen or received the recruitment materials.

We had a limited number of smartphones available to loan; most participants were required to provide their own. Participants were asked to keep the application running for two weeks and validate at least five days of data. As mentioned, participants received a SG$30 (US$25) award for fulfilling all requirements. While we made efforts to broadly represent the Singaporean population, the basic requirements for participation (access to a smartphone and computer) and the difficulty for us to reach older adults, those with lower English comprehension skills, and persons not in professional trades resulted in a fairly skewed pilot group. In general, the pilot sample was young, highly educated, with low automobile ownership rates (Figure 5). Of the 74 initial persons who completed the pre-survey questionnaire, less than 50% (34 persons) installed the app and collected data and only 36% (27 persons) actually validated their data. We suspect several reasons for this attrition rate. First, since at the time the pilot survey began neither the Android nor iPhone app were available on their respective public markets, users likely faced difficulty in accessing and installing the app. Second, the participation process – from signing up with the pre-survey, to installing the app, to running the app, to validating collected activity and mode data – was unclear to users, a point derived from conversations with users and usability tests. While we followed up via email with those persons who registered but did not collect data, few persons responded to these contacts.

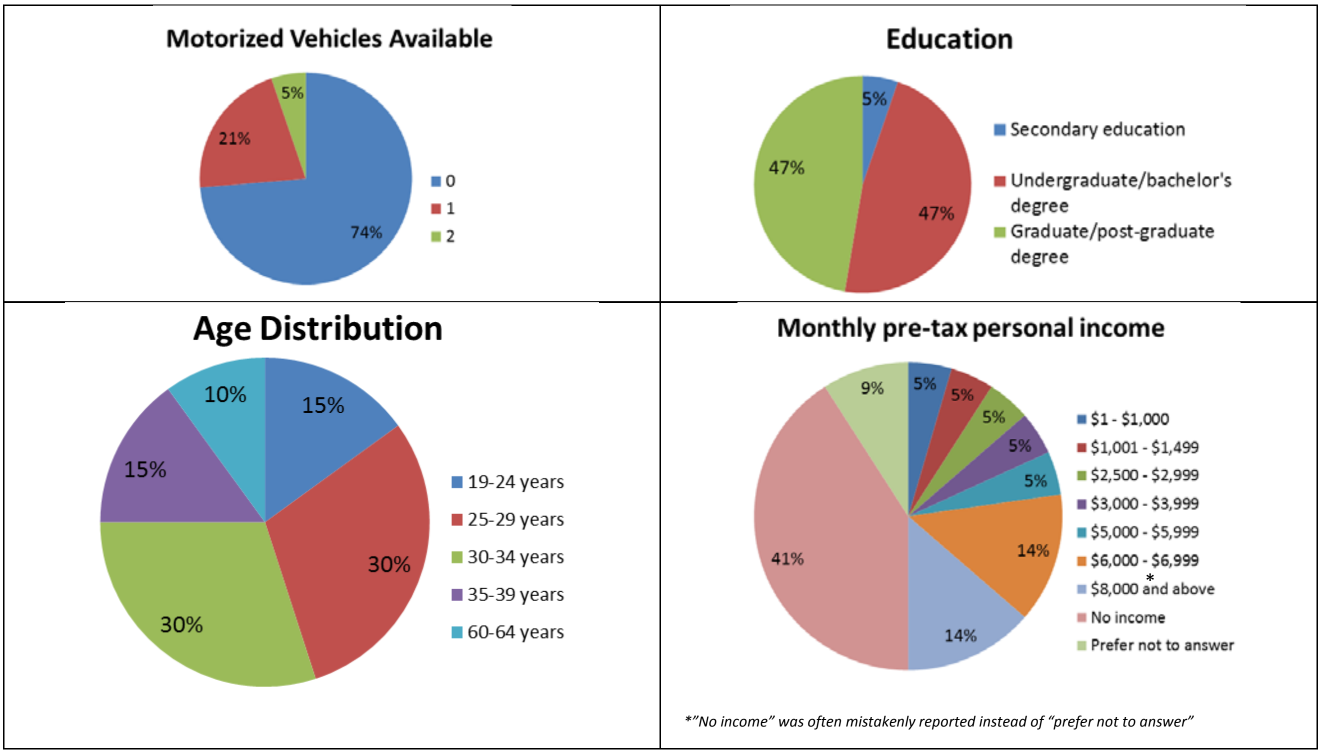


Figure 5: Demographic breakdown of registered users who collected and/or validated data (N=34)

As of July 2012, over 30 persons had actively collected and/or validated data as part of the pilot study (the number has fluctuated, as additional persons have joined the study or stopped collecting prior to completion of the pilot requirements). While we requested that participants run the survey app for 14 days and validate their activities and modes for five of those days to receive the incentive, we found that many persons continued to collect and/or validate after their participation was complete. Of the active participants, roughly 68% validated more than the required five days of data, with an average of 60% of their total identified activities validated. Such involvement suggests that some participants may become interested in the survey process, or may enjoy having a record of their activities. Of course, those persons who followed through with registering, installing, and using the app may simply be more interested in the app and its services than those persons who registered but did not fully participate.

Findings

The pilot study did not provide a statistically valid sample but the overall experience provides a number of findings useful to our ongoing development of FMS and, possibly, for similar initiatives, including:

- Non-intrusiveness: Once installed on the phone, users tend to forget about the existence of the app and need explicit reminders to conduct further interaction (e.g. turn GPS on, use the website); some users uploaded several days of data without ever visiting the website.
- Battery life: Battery life poses a major challenge, partly mitigated for users who mostly stay indoors (lack of GPS availability reduces use of this sensor and associated battery drain) and/or for those accustomed to charging their phones at work. The Android application generally performed better than that developed for the iOS platform. We recorded battery life in the range of 10 to 24 hours, generally requiring at least one recharge per day, although further analysis is necessary.
- Phone performance comparisons: Internal to our team, we conducted multiple-day tests of operating system and phone performance (i.e., individuals simultaneously carried two phones, either an iOS- and Android-based, or two Android-based), using HTC Wildfire S, HTC Sensation, and Galaxy SII for the Adroid app and iPhone 3GS, iPhone 4, and iPhone 4s for the iOS platform. We found that, even with the exact same type of phone and settings, data quality may differ considerably. Possible explanations include GPS noise, interference with the human body (by placing the phones in different places/positions), and difference in the initial GPS clock settings. Furthermore, the two phone platforms have significantly different locationing technologies (e.g., iOS groups WiFi, GSM and GPS in the same “location” software package, transparent to the programmer).
- Prompted-recall: For routine travel, user recall capabilities tend to be limited to only a few days, particularly regarding start/end times and mode. On the other hand, people can apparently relatively easily recognize past locations and activities when looking at their traces.
- Validation detail: Only experienced or highly engaged users added new locations, even when these locations were clearly missing in the information provided to the user from the background intelligence (e.g., alighting from the bus and walking home is considered an activity in our survey but is sometimes missed by the background intelligence). On the other hand, users comfortably deleted wrongly detected locations, leading us to prefer detection of false positives over false negatives, within reason (e.g., presenting too many locations for a day will generate an intimidating interface).
- Map interaction: As expected, some users prefer map interaction while others prefer text. An ideal interface would allow the same type of interactions in both modalities.

- Zoom level: An important aspect at each moment is the zoom level. A high zoom level allows the users to carefully verify location but loses context, a low zoom level provides context but can mislead the user with precise location. Here our interface provides a compromise by initially zooming to the previous, current and subsequent activity locations. This can lead to varying degrees of zoom depending on longest distance, and thus various degrees of location error.
- Participation experience: Usability tests and the pilot users generally suggested that overall participation was fairly simple, although frustrating at times, especially during the first few interactions. Even technology-savvy people seemed to face a fairly steep learning curve.
- Privacy concerns: Some users did manifest privacy concerns, either by refusing to invite other household members (e.g. spouse) to participate or by only participating for the minimal set of days. Interestingly, when asked about future sharing of their own data for other research purposes, they rarely opposed.

From these findings, we now distill a few key lessons:

- *User comprehension*. Even with detailed materials and explanations, new users often found it hard to understand their tasks and responsibilities for the survey and the relative importance of the necessary data type and detail. For example, what is the difference between an activity and a trip? The need to answer these and other questions "generically" (i.e., in a way understandable to most users) through the interface design and information provided is higher than with face-to-face interaction.
- *Simplicity:* Not having a simple process by which recruited persons could access the app (i.e., presence in an app store) proved a barrier to participation. At a very late stage, we tested the inclusion of the Android app in Google Play (the Android app store), which revealed that simplifying the process for installing the app and registering with the survey will likely encourage participation. In addition, the initial workflow requiring the user to register online, respond to an email, install the app, and then return to the website to validate their data in the activity diary proved too complex. We have since developed a new workflow for the Android phone – whereby the user may directly access the app in the Android app market, register on his or her phone, and begin collecting data immediately – which aims to greatly simplify the process for the users'.
- *Balance between data need and user burden*: The primary trade-off is between data collection and battery saving. This trade-off has great repercussions for the user's experience with the survey, both in terms of expected ability to use the phone as usual and in the ability to see clear activity traces on the online map. We used phased sampling, designed to respond to the user's likely behaviors in terms of activity periods as the primary attempt to strike this balance..
- *Continuous learning:* A key point in the development of the FMS system was to make the website and interface as intuitive as possible to the user. However since we are aiming for a diverse audience, this ideal balance may not exist. More importantly, users that look at FMS for the first time will need a more information-intensive interface than those who use it regularly. Ideally, the interface should gradually change according to the user' expertise.

These lessons will be carried over as we work towards the next portion of the FMS survey process.

Next steps

The next developments aim towards maximizing the LTA HITS survey results and preparing the survey for straightforward implementation in other locations worldwide. Our priorities generally fall into the following three categories.

- User simplicity:
    - iOS (Apple) market. Gaining entry to the iOS market requires more "user" functionalities for the app, such as providing a map of the day's activities or statistics on distance walked, requiring some adjustments to the app and interface.
    - Step-by-step activity diary tutorial. Due to the steep learning curve, plans to provide a detailed walk-through tutorial upon first logging into the activity diary are underway.
    - Automatic email reminders. Provide automatic email reminders to users to re-start the app if data collection requirements are not completed or to log into the activity diary if sufficient days have not been validated.
- Background intelligence:
    - Allow individualized phased sampling. Currently, the algorithm is tuned to maximize travel capture according to the entire population (e.g. intensive data collection from 8 to 10 AM and 4 to 7 PM to capture commuting trips) but this may be tailored to match individual routines.
    - Use location context to improve sampling capability. For example, knowing that one has arrived at work may indicate the need for less aggressive GPS sampling.
    - Improve map-matching capabilities to increase mode detection precision.
    - Integrate location and accelerometer data with bus/subway stop location information to improve smooth "change mode" detection capabilities.
- Interface and activity diary improvement:
    - Exploit color in icons to overcome visualization limitations by, for example, grouping icons by theme.
    - Exploit map api capabilities (e.g. right click to open interaction boxes) to increase map interaction capabilities for tech savvy users.

Conclusion

The Future Mobility Survey is a novel smartphone-based, activity survey currently being deployed in the Republic of Singapore. The design, development and implementation of the survey system (including the smartphone application, activity diary and website) have required an extensive period of testing and evaluation of trade-offs in order to develop a practical system, easily understood by participants, parsimonious with respect to resource use (particularly phone battery and data plans) and useful to practitioners. While the pilot implementation has not resulted in a statistically significant sample, yet, it has provided valuable insights into user needs regarding the interface, as well as training data for the background intelligence for stop and mode detection. We found a need to ensure a clear survey workflow and simple user interaction in order to maintain participation rates. This experience demonstrates both the possibilities for smartphone-based travel surveys and the effort needed for successful deployment. The participation process should be simple, with the approach striking an appropriate balance between data collection and battery life, and efforts made to ensure that the user does not feel overwhelmed by the requirements for participation.

The FMS is now being deployed as part of Singapore's latest household travel survey, with an expected 1000+ users. In this context, we plan to better test the benefits and limitations of this technology by conducting a "difference in differences" experiment, attempting to compare the FMS group to a control group (i.e., "standard" survey respondents) and in a pre-/post- fashion.. Such an experimental design will allow us to test the actual responses of persons using the FMS system, improving our understanding of the travel survey benefits promised by advanced, increasingly common, consumer products-based location-sensing technologies.

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