

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

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### **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.

## 1 Introduction

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

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

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

## 29 Background

30 While smartphone-based travel surveys are in their infancy, GPS-based surveys have been widely  
31 implemented worldwide, beginning with a proof-of-concept study conducted for the U.S. Federal Highway  
32 Administration in Lexington, Kentucky (USA) in 1996, and expanding to projects in Australia, the  
33 Netherlands, Canada, and Israel, among others (6, 3, 7, 8, 9). However, although GPS can record accurate  
34 time and geographic information of travel, participants must still provide detailed attributes such as trip  
35 purpose and mode. To collect information that cannot be derived from GPS data alone, various prompted  
36 recall methods may be used, including paper-based (10), mobile phone-based (11), and web-based (12, 13,  
37 1, 14, 15, 7, 16, 17). The type of recall method depends in part upon the type of survey being conducted, as  
38 well as the demographics of the population of interest (access to a computer, language skills, etc.). For  
39 example, Stopher, *et al.* (2007), in a Sydney (Australia) study, provided GPS survey respondents with the  
40 option to complete their prompted recall section via telephone, Internet, face-to-face interview, or mail;  
41 phone and mail surveys had the greatest percentage of completions, internet the fewest. Such findings

42 suggest that prompted recall methods incorporating some interaction between the surveyor and the  
 43 survey participant will be most successful; however, such interaction may increase both the survey  
 44 implementation cost and completion burden.

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

54 Smartphones are increasingly ubiquitous and versatile loggers. Besides GPS, they generally include a variety  
 55 of sensing technologies such as accelerometer, WiFi, and GMS, the combination of which may provide  
 56 more detailed information on traveler behavior, as well as data when GPS is inadequate for determining  
 57 traveler location. For example, the University of Minnesota's UbiActive application uses data captured from  
 58 3-dimensional accelerometer, GPS and 3-dimensional magnetic sensors to determine such inputs as  
 59 movement time, speed, and orientation in order to calculate physical activity duration and intensity (18).  
 60 Users are prompted to provide information regarding their well-being, or satisfaction with their travel, at  
 61 the conclusion of each trip. In addition, the app provides users with information regarding their physical  
 62 activity and calories burned. Smartphone-based surveys have been proposed or explored by the California  
 63 Department of Transportation (Caltrans) and District IV of the Florida Department of Transportation,  
 64 highlighting the expectations for these technologies to supplement or enhance traditional travel survey  
 65 methods. In the following section we describe efforts to develop a pragmatic "base" survey that may be  
 66 used both as a stand-alone travel survey, as well as a platform for the development of additional surveys as  
 67 more sensors and sensor applications are developed.

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## 69 **The Future Mobility Survey (FMS)**

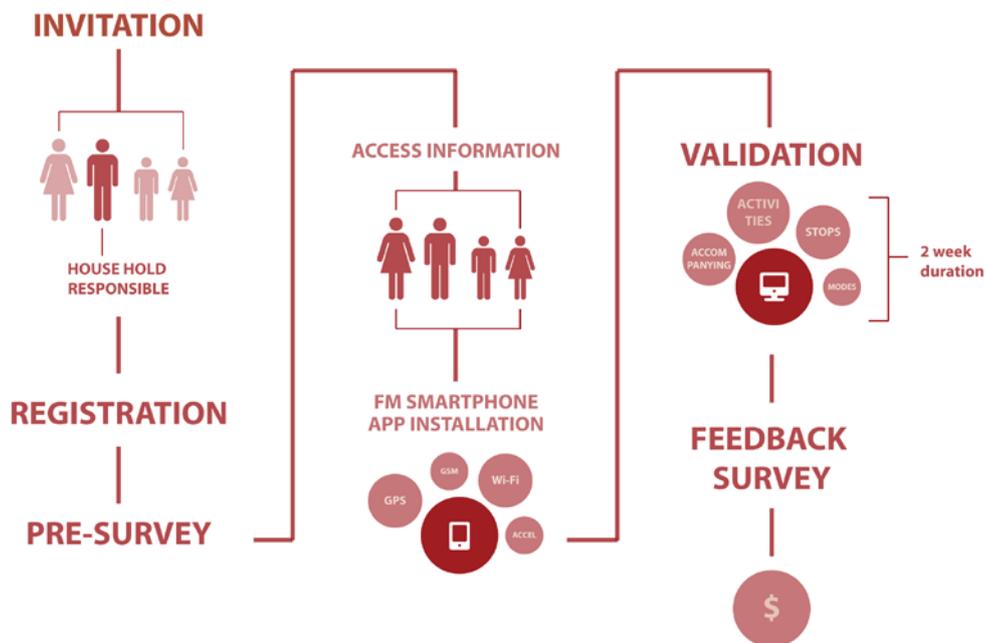
70 The FMS collects user input at four stages:

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

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

82 Workflow and technological infrastructure

83 The FMS global interaction workflow is presented in Figure 1.



84

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

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Figure 1: FMS workflow

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

89

- 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.

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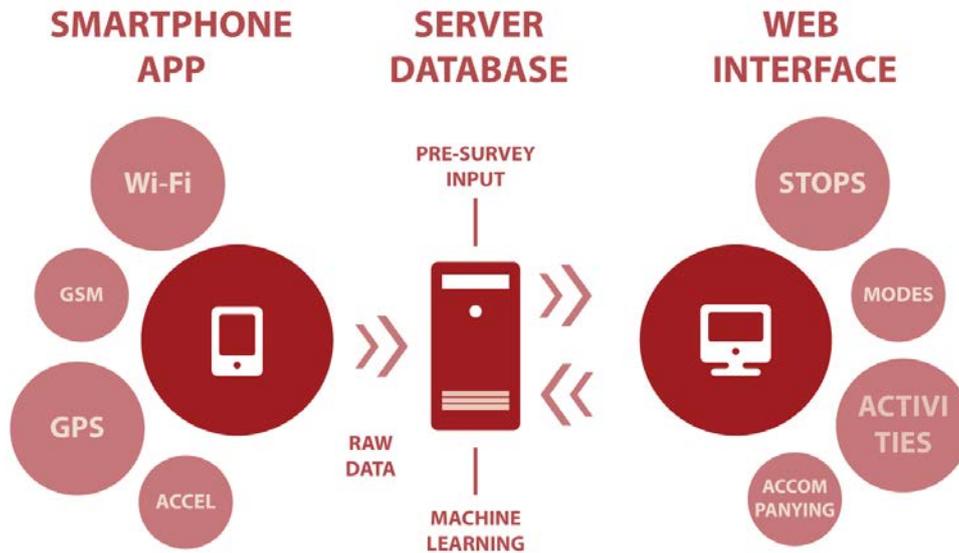
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105 We designed the process to be simple for the user, providing data and information in a clear, concise, and  
 106 intuitive way. In the background, however, lies a far more complex process, following the general

107 architecture shown in Figure 2. The *smartphone app* uploads data to the *server*, where several close to real-  
 108 time algorithms are used to prepare the data for the *web interface*, with which the user mostly interacts.



109  
 110 Figure 2: Survey architecture

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

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

128 Finally, we designed the overall user interface to satisfy three objectives: meeting modeling priorities,  
 129 satisfying a broad spectrum of user types, and minimizing technological complexity. The FMS is part of a  
 130 project to develop next-generation activity-based models; thus, we prioritized accurate data collection for  
 131 determining activities, modes, locations and routes, in this order. For example, the interface design reflects  
 132 that, for us, obtaining the precise route from A to B is less important than accurately identifying the  
 133 activities performed at and mode(s) taken to B, since ground truth for the latter is harder to capture from  
 134 sensing data. Route identification can be performed via post-processing by, for example, using probabilistic  
 135 map-matching (5) and filling gaps with route planning algorithms (e.g. Google maps API). Regarding users,

136 since the FMS is expected to function independently (i.e., with little dependence on surveyors for  
137 assistance), we aimed to develop a smartphone application and website for persons who are not especially  
138 familiar with these technologies, and/or are poor map-readers and/or dislike interacting with traditional  
139 online surveys while happily interacting with maps and icons.

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

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

#### 149 *Pre-survey*

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

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

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

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

- 170 • Mandatory versus optional question responses
- 171 • Limited question responses
- 172 • Question ordering
- 173 • Privacy and confidentiality

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

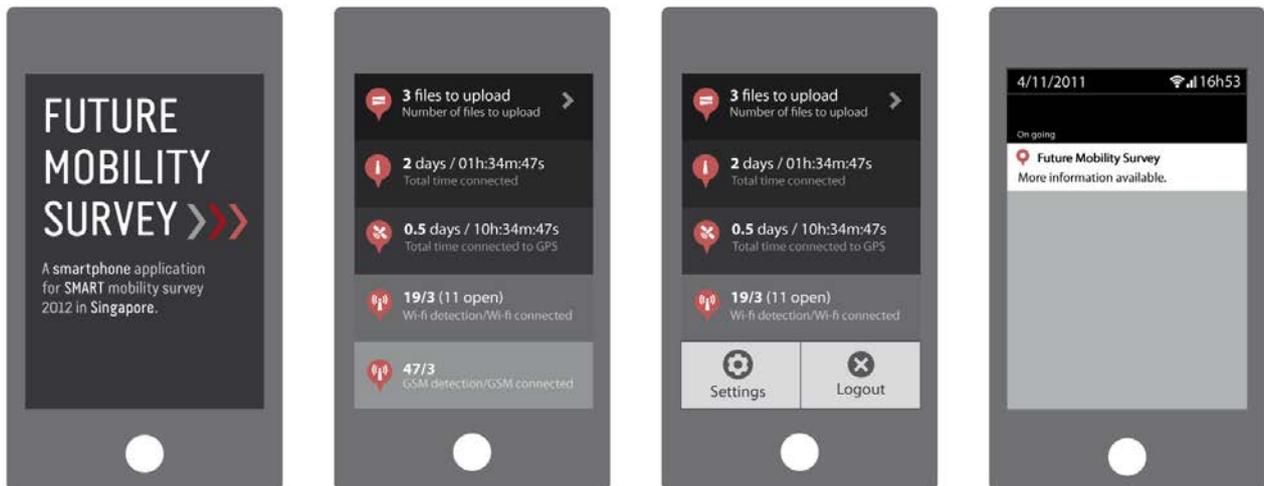
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#### 191 *Smartphone applications*

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

212 In developing the smartphone application itself, we have opted for a simple and non-intrusive interface, as  
213 shown in Figure 3. The primary interaction that the user has with the app is to sign in and sign out as  
214 necessary, though she may also choose both how to sync data to the server, and at what level of battery  
215 loss the app will log out automatically. While we have considered the possibilities for the user to complete

216 the activity diary on the smartphone app and/or for the app to provide feedback to the user, we leave  
 217 those possibilities for future evaluation, for two reasons. First, we are aiming to keep the application as  
 218 unobtrusive as possible, running in the background, to minimize battery loss and bother to the user.  
 219 Second, as our initial intention is to supplement, if not eventually replace, a traditional household travel  
 220 survey, we must minimize the instrument's influence on the behavior of interest. Although interesting for  
 221 other experimental designs, and certainly viable with modifications to our current approach, providing  
 222 behavioral feedback to the participant would run counter to our specific purposes.



223

224

Figure 3: General application interface

225

### 226 *Activity diary*

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

The figure displays three views of the 'FUTURE MOBILITY SURVEY' Activity Diary interface. The first view (left) shows the main dashboard with a map of a city area and a table of activities. The second view (middle) shows the interface with a specific location selected on the map. The third view (right) is a detailed modal for an activity, showing start and end times, activity type, and transportation mode options.

| Activity | Travelled to by | Activity Start | Activity End | Add | Delete |
|----------|-----------------|----------------|--------------|-----|--------|
| 1        | [Icon]          | 21:20          | 01:34        | +   | x      |
| 2        | [Icon]          | 01:36          | 06:09        | +   | x      |
| 3        | [Icon]          | 06:52          | 18:14        | +   | x      |
| 4        | [Icon]          | 18:35          | 18:47        | +   | x      |
| 5        | [Icon]          | 18:51          | 06:12        | +   | x      |

**Activity Details (from right view):**

- Date Selection: 24-07-2012
- Start Time: 06:52 of Current day
- End Time: 18:14 of Current day
- Activity: [Icon]
- Mode of transportation: Public bus (selected)
- Accompanying: 1 person

234

235

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

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

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

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

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

#### 261 *Exit survey*

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

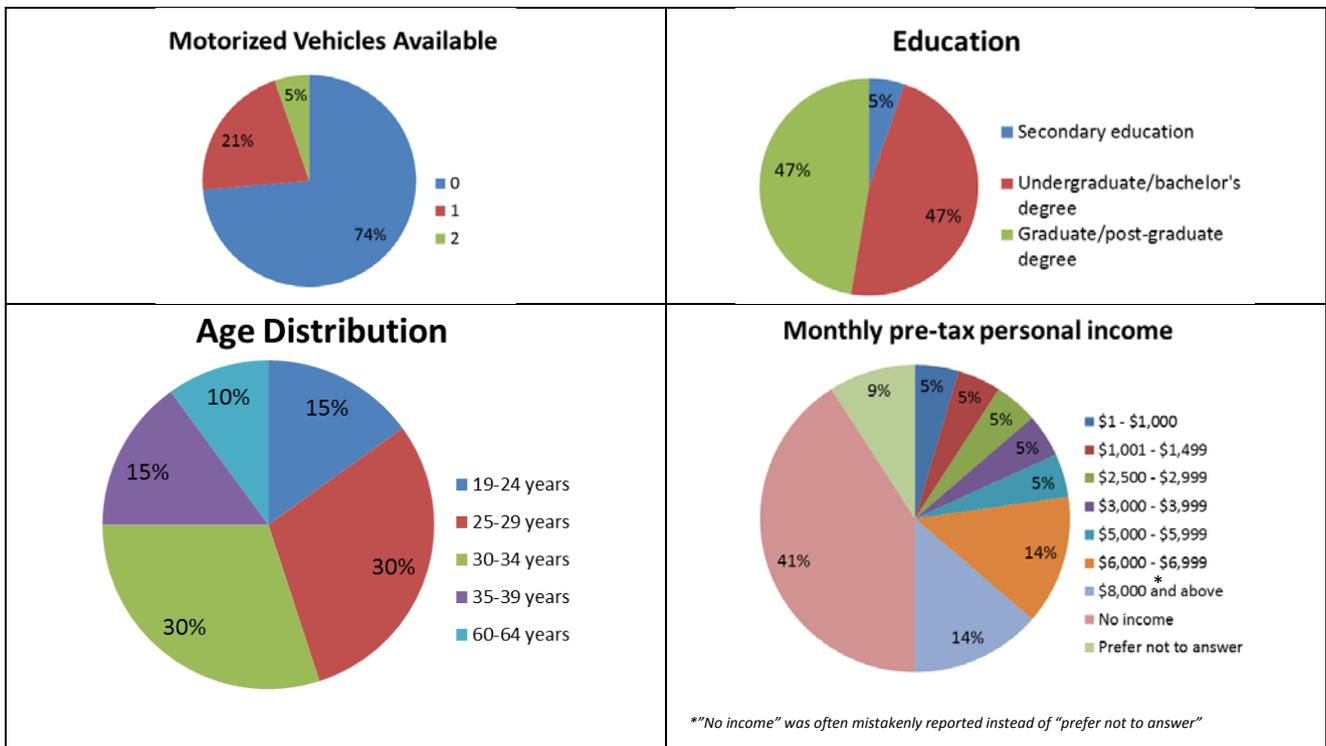
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#### 273 **Pilot Implementation**

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

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

296



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

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

### 308 *Findings*

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

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

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

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

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

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

381 **Next steps**

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

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

## 409 **Conclusion**

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

423 The FMS is now being deployed as part of Singapore’s latest household travel survey, with an expected  
424 1000+ users. In this context, we plan to better test the benefits and limitations of this technology by  
425 conducting a “difference in differences” experiment, attempting to compare the FMS group to a control  
426 group (i.e., “standard” survey respondents) and in a pre-/post- fashion.. Such an experimental design will  
427 allow us to test the actual responses of persons using the FMS system, improving our understanding of the  
428 travel survey benefits promised by advanced, increasingly common, consumer products-based location-  
429 sensing technologies.

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