Comparison of GPS Data Loggers and the Smartphone Application Route Scout for Use in GPS Data Collection for Travel Surveys

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Joint Statistical Meetings
May, 2013

ABSTRACT

The state-of-practice in Global Positioning System (GPS) data collection for travel surveys involves using survey-issued data loggers to capture GPS data, then using the data as a supplement to survey information. Recently, however, smartphone applications have been developed to combine some of these steps and reduce both the respondents' and surveyors' burdens. This study investigates the current practice of and future for GPS data collection with a comparison of data loggers, the smartphone application Route Scout, and the methods by which each type of data is processed. The objective of this paper is to show the benefits and hindrances of smartphone technology in relation to data loggers and to discuss specific examples and possible future developments. The technologies were tested side-by-side and evaluated on the quality of the raw data collected, monetary and time investments, storage capacity, battery usage, processing methods, and versatility. With respect to each of these concerns, it can be determined that smartphone applications have the potential to become the preferred method of GPS data collection in travel surveys.

INTRODUCTION

Nearly any type of data can be put into a geographic context. When studying the movement of people and things from place to place, Global Positioning System (GPS) data is invaluable. Travel surveys in particular have in the last decade or so been utilizing this technology to obtain a more precise and accurate picture of people's travel behaviors using travel path, time, date, and speed. As technology is ever advancing, so are GPS collection methods. With the introduction and rise of smartphone technology, GPS has become more accessible to people who previously would not have had such tools. The majority of households in the US now has access to this technology. As has been suggested in previous literature, smartphones have become a good alternative to conventional GPS data loggers that are designed only for GPS data collection. Though this has become a more prevalent way of thinking, the technology has not been seen much in the travel survey industry. The purpose of this paper is to show the reasoning behind this shift in thinking by testing a smartphone GPS data collection application and conventional data loggers side-by-side and evaluating their performances based on the quality of the raw GPS data, monetary and time investment costs, storage capacity, battery usage, data processing methods, and versatility. We will also discuss the challenges that come with using such technology in place of GPS data loggers and solutions for those challenges, and will look into possibilities for the future.

DATA QUALITY

The origins and destinations of a person's trips as well as the mode, time of day, day of the week, and route for those trips are of great importance to metropolitan planning organizations (MPOs) and departments of transportation (DOTs) when modeling and can be used in many other disciplines, such as market research. Many current travel surveys use passive GPS data loggers supplemented by travel diaries and Computer Assisted Telephone or Web Interviews (CATI, CAWI) to gather this data. A benefit to conducting a smartphone-based survey is that GPS and diary data can be combined into one step using an interactive application. For the sake of data comparability in this study, however, a passive smartphone GPS application called RouteScout was used alongside a passive GlobalSat DG-100 GPS data logger, and the results examined.

A travel diary was kept for the period in which the devices were being tested, and recording frequency for these devices was set to use spatial rather than temporal sampling. The value for recording frequency was set at 60 meters as it reduces the amount of points collected while stationary and allows the devices to conserve battery while still yielding GPS traces that can be used to impute trips. The data collected by each device includes latitude, longitude, time, date, altitude, accuracy, and speed. Testers were also asked to write down notes on battery life, environmental factors, and any other things they thought might affect the data. The data logger and smartphone application were to be turned on at the same time, then left running for 48 hours. After the collection period ended, the GPS traces were loaded into a Geographic Information Systems (GIS) program and compared with each other and with the geocoded travel diary addresses.

The differences lay in the Time to First Fix (TTFF), or satellite acquisition time, and the accuracy values for each technology. A delay in signal acquisition can greatly affect the starting point for each trip. A GPS unit that is turned on for the first time (cold-start) will not have any previous location information and will need to locate satellites to begin recording. A unit that has been woken up from sleep mode shortly after recording activity (warm-start) will also need to locate satellites, but will recall the last recorded location trace. A hot-start is when the device remembers both the location and satellites that were used in the last recording session and is able to communicate with satellites to record a location trace in as little as one second. Average start times for both technologies are recorded in the table below. They were calculated based on the difference between when the trip origin was departed from and when points began to be recorded.

Table 1: Average Time To First Fix (TTFF) in Seconds

	Data Logger	Smartphone
Cold Start	42	5
Warm Start	34	2
Hot Start	3	1

The delay in TTFF associated with cold and warm starts causes the GPS points at the beginning of a trip to be missed. On one trip in particular, the data logger did not collect data until nine minutes into traveling. This was the longest delay, taking place in a moderately hilly area and causing the first recorded location trace to be over 1600 meters straight-line distance and 4800 meters travel distance from the actual starting point. Another delay in signal acquisition was seen after leaving a lower-level parking garage with little to no satellite visibility. Signal was acquired 91 seconds after leaving this location, and the beginning of the trip was cut off. Despite the option for automatic sleep mode having been turned off on all of the data loggers used, this delay of signal happened for a good deal of data logger recordings, as 8.8% of the trips were recorded as starting more than 60 meters from their true-to-life beginning locations.

The smartphone application was able to acquire location as soon as the phone acquired cellular signal. This is due to the fact that smartphones use Assisted GPS (AGPS) to calculate positions, using cell tower or Wi-Fi network triangulation as well as downloading scheduled satellite routes. With triangulation, the phone's location is found using its distance from at least three known cell tower or Wi-Fi locations, drawing a circle with that radius around each known location, then finding the intersection of the circles (1). The fact that most cell phones are on and being used for the majority of the day means that the phone is almost always connected to the cellular network and is able to receive information nearly instantly (3). The result of this AGPS data coming from many different sources, however, is that the accuracy radii for the traces vary more and are somewhat higher than those from GPS data loggers. The data loggers in the study did not have accuracy radii larger than 20 meters, while smartphones had accuracy radii ranging from 1-200 meters. Though the accuracy range is much larger for smartphones, 85% of the traces had an accuracy radius of smaller than 30 meters. There were no RouteScout recordings that began more than 60 meters from their true-to-life locations, and only one out of 22 trips showed signs of smartphone accuracy affecting the recorded path.

A heterogeneous study combining two types of data collection device might encounter data comparability problems, but both the data loggers and smartphone applications in this test were configured to collect at the same interval, which reduced the discrepancies between the two types of raw data. The main difference seen in the study data was the change in starting location for some trips due to a delay in satellite signal acquisition, which can happen with any GPS device but less often with smartphone AGPS as it combines multiple methodologies to record location data. Overall, both devices provided very precise travel paths, even the smartphone data with larger accuracy radii.

MONETARY AND TIME INVESTMENTS

When deciding between GPS data collection devices, one of the main concerns is cost. In addition to the cost for the devices themselves, a surveyor must take into account any additional survey materials that may be sent out, the deployment shipping for those materials, recovery shipping, the inevitable loss of equipment, and the time that it will take to produce usable data.

Approximate cost for the devices (or licenses) and shipment in a homogeneous data logger (DL) survey as compared to a homogeneous smartphone survey and a heterogeneous smartphone/data logger survey for 2000 respondents are listed in the table below.

Table 2: Cost Comparison for Homogeneous Data Logger, Homogeneous Smartphone, and Heterogeneous Data Collection

	Homogeneous	**Homogeneous**	**Heterogeneous**	
	Data Logger	Smartphone	Data Logger	Smartphone
ONE-TIME COSTS				
Application Use per Device (one week)	$0	$15	$0	$15
Device Cost	$75	$0	$75	$0
Devices in Use per Wave	100	2000	100	996
Total One-Time Cost	$7500	$30000	$7500	$14946
RECURRING COSTS				
Shipping Cost (Two-Way)	$38	$0	$38	$0
Shipments per Wave	100	0	100	0
Total $ per Wave	$3800	$0	$3800	$0
Number of Waves	20	1	10	1
Total Recurring Cost	$76000	$0	$38137	$0
Grand Total $ for All Waves	$83500	$30000	$45637	$14946
Grand Total $ for All Waves (Heterogeneous Added)	$83500	$30000	$60583	
Percent Savings for Homogeneous Smartphone Survey Compared to Homogeneous DL Survey	64%			
Percent Savings for Heterogeneous Survey Compared to Homogeneous DL Survey	27%			

Homogeneous data logger surveys with large numbers of participants require recycling and rotating a GPS unit to a new respondent after it has been used by one respondent and its data uploaded and cleared by the surveyor. This requires a good deal of manual labor in shipping and uploading the data, but is done so that only a small number of data loggers need to be purchased at a time, and device expenditures can be kept low. In a 2000-person survey with 100 available data loggers, there will need to be at least 20 waves, spaced out so that there is enough time to retrieve and upload the data from each. Waves could also be split further, with the first half going out one week and the second half going out the next to allow a week for the first half to be returned. This would eliminate the time between waves allotted for returning devices. Having multiple waves of data collection increases the time necessary to conduct the survey, but it also reduces the amount that will need to be spent on the devices themselves.

In homogeneous smartphone surveys, the surveyor incurs no costs related to the shipping of materials as everything is transmitted over wireless cellular networks. The surveyor also does not need to take into account maintenance or replacement of damaged, lost, or stolen devices because the respondent uses his or her personal smartphone to record data. The per-device fee for use of the application is the only cost related to GPS data collection and will vary from developer to developer. It is often inversely related to the number of devices that will be using the application, includes data monitoring, and covers a specified amount of time. Use can be monitored and controlled using login Personal Identification Numbers (PINs) and activating or deactivating them for use with the application. Because this is the only cost related to smartphone data collection, all of the respondents are included in one wave in the table. Depending on the capacity of the developer's servers for handling such large amounts of data, these may need to be split into smaller groups. A GPS survey conducted entirely through smartphones can save the surveyor around 64%, but will change depending on the stated variables.

According to The Nielsen Company (2), approximately 94% of Americans own a mobile phone, and of those 94%, approximately 53% own smartphones. These figures are used to calculate the number of smartphone and data logger users in the cost approximation for a heterogeneous study (above). A study of this sort would still cost less than a study done entirely with data loggers, saving the surveyor approximately 27%.

The best case scenario for data delivery using GPS loggers is approximately 15 days per wave. The bulk of this time comes from shipment of the devices to and from the respondent (six days total). Also included in this time estimate are a three-day travel period, manual data uploading (two days), trip imputation (two days), and data delivery (one day). There should also be a day or more buffer between the shipment arriving and the travel days, so that it is assured that the respondent will receive the devices in time.

For delivery of complete and cleaned data from a smartphone application, the best case scenario is approximately six days. This is due to the fact that the time it takes for downloading the application is negligible and that the collected information is uploaded in real-time from the respondent's smartphone to the data server so all shipping time and data uploading time is eliminated.

STORAGE CAPACITY

Because their data is manually uploaded to the server and cannot be dumped wirelessly, data loggers have a limited storage capacity. When set to record every 60 meters, the loggers tested were able to capture an average of 60 hours' worth of data. If a respondent travels more, more location traces are collected and the logger's storage capacity is used up faster and vice versa. Other data loggers on the market can record from 16 to 100 hours' worth of GPS data at a rate of one trace per second. Cheaper models often record smaller amounts and are better suited for short-term surveys in which data is collected for 1-2 days.

On the other hand, smartphone applications work well for data collection over extended periods. Once connection with a wireless or cellular network has been established, a smartphone's recorded GPS data is uploaded to the server and deleted from the memory. This keeps the storage space used by the application at a minimum, so collection can be done for extended periods, from days to weeks or months. A smartphone can potentially transmit unlimited amounts of data; with the only limitation being the size of the server dedicated to housing all of the uploaded information. Prior to collection, however, the server is volume-tested to make sure that the expected amount of data can be housed comfortably. Developers estimate that for an average travel day of 30 miles, current smartphone applications transmit approximately 4.2 Mb of data each month when running continuously. As many smartphone data plans provide a minimum of 200 Mb of data every month, data collection applications use a maximum of 2.1 percent of a respondent's monthly allocation for transmitting location traces.

BATTERY USAGE

GPS data loggers have long-lasting batteries because they are not interactive. Even so, respondents are asked to charge the device at night or when they are not traveling so that there is little chance that the battery will die during data collection. Most data loggers can also be charged on-the-go using a car charger. Testing indicates that a data logger charge will last for around 48 hours of continuous use. This can be increased by turning the data logger off after arriving at home for the evening and then turning it on again in the morning before leaving, which requires the respondent to remember to do so.

Smartphone GPS applications collect data through the phone's built-in mapping application and do not add an entirely new GPS detection program. This works well with the smartphone's internal battery management capabilities and does not drain the phone's battery any faster than having a mapping application open would. An iPhone with RouteScout running in the background and few other applications will last a maximum of eight hours. The application code has been optimized to use the least amount of resources possible to yield maximum quality output and only accesses GPS data when the phone's accelerometer recognizes that the phone is in motion, so when stationary the application will use less battery than if the GPS were enabled at all times. On average, RouteScout collects a point every 6.5 seconds as opposed to one or three second intervals as previous GPS surveys have chosen. Because collection is distance based, the frequency goes up (every 2 seconds) when the device is moving faster, and down (every 11 seconds) when the device is moving slower. This means that the farther and faster the respondent travels, the quicker a smartphone's battery will be used up. Closing unused applications also helps to prolong battery life, and it has been shown that smartphone owners are accustomed to keeping track of their phone's battery levels and charge their devices as needed, so complete battery drain is uncommon (3).

DATA MANAGEMENT AND PROCESSING

GPS data requires processing to yield origin and destination (O/D) points before it can be used in analysis. The data logger must first be connected to the surveyor's server so that the device's information can be uploaded. After the files are saved and formatted properly, the GPS data must be split into trips either manually or using a tool programmed to recognize O/D points and validate the points between as trips. Survey and trip information comes from paper diaries and either Computer-Assisted Telephone Interview (CATI), Computer-Assisted Self Interview (CAWI). Paper diaries must be scanned and entered into digital tables by hand, while CATI and CAWI produce the tables automatically. The diary-recorded trips and survey answers must then be appended with processed GPS data to produce relevant, meaningful location and survey information. Smartphone location traces collected with passive devices must be processed similarly to logger data; however the real-time updating of information on the server helps to reduce the amount of manual labor that goes into collecting, formatting, and saving the data.

Trip imputation tools are becoming more and more sophisticated and are able to impute some of the relevant diary data; programmers have given them the ability to distinguish mode of transportation and trip purpose in addition to origin and destination points (4). These tools can be set to exclude abnormal points, such as those with very high accuracy radii or other anomalous data such as latitude of zero and longitude of zero (which is sometimes recorded as the GPS is restarted) and those location traces that jump outside of the normal path, causing unnaturally high speeds from point to point. They also need to be calibrated to work with the specific type of data for which they are being used. For instance, the trip detection tool programmed to work with RouteScout GPS output will work with any GPS data set at 60 meter intervals with the same parameters recorded, so we were able to use it with data logger output with very similar results. The tables below show the travel diary along with the RouteScout and data logger trips that were found with the same trip detection tool.

Table 3: Comparison of Trips from Trip Detection Tool for One Respondent

TRAVEL DIARY

Actual Trip ID	Origin	Destination	Start Time	End Time		Time (mins)
1	Home	Private Residence	7:45:00	8:01:00		16
2	Private Residence	Gas	8:01:00	8:15:00		13
3	Gas	Work	8:24:00	8:28:00		4
4	Work	Rental Car Drop Off	8:30:00	8:41:00		11
5	Rental Car Drop Off	Work	8:51:00	9:08:00		17
6	Work	Grocery Store	15:40:00	16:02:00		22
7	Grocery Store	Home	16:51:00	16:57:00		6
8	Home	Work	7:24:00	7:59:00		35
9	Work	Salon	14:32:00	14:51:00		19
10	Salon	Home	17:43:00	17:56:00		13

ROUTESCOUT

Imputed Trip ID	Origin	Destination	Start Time	End Time	Dist (miles)	Time (mins)
1	Home	Private Residence	7:46:17	8:16:37	11.2	30
2	Gas	Work	8:24:50	8:27:21	1.1	2
3	Work	Rental Car Drop Off	8:30:39	8:41:00	4.3	10
4	Rental Car Drop Off	Work	8:51:06	9:05:50	4.9	14
5	Work	Grocery Store	15:40:35	16:02:44	16.3	22
6	Grocery Store	Home	16:51:48	16:57:22	0.5	5
7	Home	Work	7:26:22	7:56:43	15.3	30
8	Work	Salon	14:33:18	14:51:28	9.7	18
9	Salon	Home	17:43:47	17:56:18	7.7	12

DATA LOGGER

Imputed Trip ID	Origin	Destination	Start Time	End Time	Dist (miles)	Time (mins)
1	Home	Gas	7:46:29	8:15:15	10.8	28
2	Gas	Rental Car Drop Off	8:24:47	8:37:29	5.5	12
3	Rental Car Drop Off	Work	8:51:04	9:07:35	4.8	16
4	Work	Grocery Store	15:39:54	16:01:54	17.1	22
5	Grocery Store	Home	16:53:53	16:56:26	0.6	2
6	Home	Work	7:24:13	7:56:53	15.9	32
7	Work	Salon	14:33:15	14:51:33	9.8	18
8	Salon	Home	17:44:14	17:56:21	7.8	12

This tool (used both times with the same parameters) was able to detect origins and destinations of trips for both data logger and RouteScout data, but due to the nature of the specific devices, some O/D points were missed in each data set, effectively joining two trips together. The trip detector missed 3/39 stops in the smartphone data and 2/39 in the logger data. These missing O/D points were quick pick-ups and drop-offs that did not meet the three minute threshold that was set to detect stops. Lowering this threshold to 2 minutes or less would cause more delays such as traffic lights and traffic jams to be recognized as stops, and is not recommended. Because two of the five missed stops were at the respondents' work locations, they can be recognized by incorporating into the automatic processing the use of a habitual locations table showing work, home, and/or school addresses. Points within 60 meters of the geocoded habitual location can be inferred to be a stop, even if the data does not readily suggest that they are. Recognizing the three remaining points as stops requires diary or respondent input.

OTHER CHALLENGES AND VERSATILITY

- Data Loggers are still necessary in reaching lower-income populations and higher age-groups. Any household can participate in GPS data collection using a data logger. As the devices are provided by the surveyor and can be carried on one's person, the respondent does not need to own any particular equipment in order to participate in the study. This allows the study to have a greater reach than one using only smartphone GPS data. However, though only 53% of mobile phone users in America currently own smartphones, a study done by Nielsen in June of 2012 shows that 90.9% of new phone buyers are opting for smartphone, so this number will continue to increase (5).

- While the smartphone application that was tested for data comparability was passive, there are other versions and other applications available which require more respondent input and can collect trip data as well. The active version of RouteScout asks respondents to begin each trip by answering questions about mode and purpose, then end the trip when they have stopped. It also has a page dedicated to collecting demographic information. Specific questions can be added or removed so that the surveyor can ensure that the appropriate information is being recorded. This allows applications to easily be tailored to suit a surveyor's needs.

- Smartphone applications can be programmed for multiple operating systems to accommodate a wide variety of smartphone users. Currently, 88% of users can be reached by programming applications to work with only two different platforms, iOS and Android (2). Technology is constantly changing and with new phone versions and updates to operating systems being released almost monthly, it can be hard to keep up with everything. Small changes from upgrade to upgrade might cause parts of the application code to malfunction, but working closely with a developer who is keeping up-to-speed with all of the current and upcoming modifications to popular smartphones and testing those phones makes a world of difference. This way, any modifications that may need to be made to the application's source code can be anticipated and tested before potentially becoming a problem. A developer who has in-depth knowledge of your industry and can work closely with the surveyors is ideal as he or she will be able to better understand your data collection needs and how they fit into the bigger picture.

- On Board Diagnostic (OBD) devices are known to be useful in GPS surveys for collecting information on fuel consumption and efficiency. In addition to many other Bluetooth and wireless devices, OBDs are available which may be used in conjunction with smartphones. These applications interact with the GPS collector application as opposed to simply logging information that needs to be uploaded separately. The smartphone works with the OBD through the phone's Wi-Fi connection to transmit diagnostic data to the server wirelessly and in real time, linking it with the phone's GPS data.

- Some respondents tend to feel like their privacy and personal information is at stake when they use smartphone applications. Providing a privacy and confidentiality statement in the application and on the survey website is a good way to assure respondents that no information will be harvested in the background and that the information that is collected will be used for research purposes only. All data will come from either the GPS receiver or the answers that the respondent willingly gives in response to survey questions.

- Smartphone applications are more environmentally friendly. They eliminate data logger shipping materials and digital trip information collection reduces the need for paper for travel diaries.

- When a respondent forgets to activate his or her data logger before beginning the travel days, there is no way for the surveyor to know until the device has been returned and the data is missing. In our test, two of the five respondents forgot to turn their loggers on until they reached work on the first day. This caused a loss of logger data for four trips. With smartphone technology, updates are in real-time and data collection can be monitored on the back-end by a data monitoring process. This means that if the process recognizes that no data is being collected for a respondent during his or her assigned travel days, it can send a text message reminding the respondent to log in to the application. The reminder text message will be received once the phone has been turned back on after dying or being turned off.

CONCLUSIONS

- Smartphones' Assisted GPS makes signal acquisition faster, allowing for recorded O/D points that are closer to the actual origin or destination, while data loggers provide traces with, on average, smaller accuracy radii than smartphone traces.

- For small and large studies, the use of smartphone applications for data collection can significantly reduce cost. The only monetary factor in data collection with smartphone AGPS is often the per-device usage fee. A survey using data loggers, on the other hand, incurs shipping costs and will also need to take into account the possibility of lost or stolen devices.

- In addition to the higher monetary costs associated with data logger shipping, time is also needed to deploy and retrieve the devices. These units dictate a longer duration for larger volume surveys, as the costs of purchasing GPS data logger devices is minimized when collection is done in waves.

- Conventional data loggers have limited storage capacity and can collect a maximum of three days' worth of continuous GPS data before the memory will need to be reset. Shutting the logger off when stopped for long periods or having this set to automatically happen will increase the storage capacity. Smartphones have unlimited data collection capabilities as the data is transferred directly from the phone to the server and not stored on the phone for longer than it takes for the phone to receive cellular or Wi-Fi signal.

- Data loggers have batteries that seldom need to be charged, lasting nearly two days. Smartphone batteries do not last nearly as long, with the maximum amount of time that a smartphone can run with GPS activated being around nine hours. This number decreases with use of other applications, but is maximized by programming the GPS application to use minimal resources.

- Management of data logger data must be done manually, as the device needs to be physically connected to the server in order for the data to be uploaded. This takes extra time and labor, while smartphones upload in real-time and the data gathered is automatically added to the database. Processing of both data logger and smartphone data can be done using trip imputation systems designed for use with GPS data. Parameters for these tools must be set at appropriate levels for working with the specific mode of travel and collection device.

LOOKING AHEAD

The adoption of smartphones for GPS data collection has many implications for the future of travel surveys. Applications can easily be altered to accommodate the specific needs of different surveyors and will continue to evolve as travel surveys do.

With the introduction of smartphone location collecting applications, long term studies are now more feasible. Smartphones can transmit unlimited amounts of GPS data with no need for return shipment to upload data and clear the device's memory. This allows collection to continue without interruption for as long as necessary and exponentially reduces the costs for long-term studies. As they provide the potential for surveys to be done entirely through the respondent's personal smartphone, no additional survey equipment needs entrusted to or collected from the respondent. Though with the development of trip imputation tools, a travel diary is not necessary to match trips with GPS data, the diary and demographic data still prove useful in modeling and is still retrievable through active smartphone applications. In this manner, the digital diary will be able to accommodate more in-depth travel diary information over a period of time greater than the one day that the current paper diary is tailored to. Longer data collection periods can be expected to yield less variable and more comprehensive travel data.

Applications also have the potential to become more automated and require little to no supplementary data or respondent interaction by using algorithms to link highway and map information with GPS coordinates and heading to record directions, street and place names for each trip (3). Trip imputation tools in which mode and purpose are imputed can in the future be integrated directly into the application itself, analyzing the points as they are collected and allowing the respondent to validate the detected trips in-app by editing them or inserting a note identifying a missed trip. This incorporation of the collection of both calculable and incalculable data reduces discrepancies between respondent reported and GPS recorded trips, which lessens the data processor's reliance on trip correction factors to make up for those discrepancies and increase data quality.

The employment of smartphone GPS data collection applications offers the opportunity for surveyors to collect as much complete and correct information as possible through one medium and with minimal burden to both the surveyor and respondent. Data loggers will continue to be an important method of GPS data collection, but smartphone use is ever-increasing and these devices should be utilized for all of the potential that they offer to those conducting travel surveys.

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