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Smartphone app versus GPS Logger: A comparative study

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Abstract

This paper describes a study in which a smartphone app and dedicated wearable GPS devices were used in the same study, with processing done with the same software, providing an opportunity to determine the strengths and weaknesses of each. The study found that respondents were more willing to accept the dedicated GPS device, were more likely to comply with the requested task, and provided an overall higher response rate with the GPS logger than with the smartphone app. After processing the data and matching the GPS data to the diary data, both technologies produced similar results in terms of proportion of trips that show a good match to diary data.

Keywords: GPS Logger; Smartphone App; GPS processing; comparative study; diary data; compliance; recruitment.

1. Introduction

Many recent household travel surveys have either included a GPS component or have been conducted entirely using GPS devices. Li and Stopher document a number of these studies, but a number of other studies have used either a GPS component, such as Chicago, Beijing, California Statewide (Kunzmann et al., 2013), Massachusetts Statewide (Massachusetts Department of Transportation, 2012), Singapore, Atlanta (Livingston, 2011), New York City, French National (Marchal et al., 2011), inter alia, or have replaced the diary with GPS, such as New Zealand Nationwide,

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Dunedin, Cleveland (Wilhelm et al., 2013), Jerusalem, inter alia. When GPS first began to appear as a subsample in a household travel survey, it was usually accomplished by using wearable GPS loggers. However, with the market penetration of smartphones and the proliferation of apps for these phones, a number of recent surveys have opted to use respondents' smartphones, providing them with an app to install for the duration of the survey. As noted by Montini et al. (2015), there are a number of reasons why smartphones have become a promising source for GPS travel data. In addition to the points made by Montini et al. (2015), there are several reasons why the method of using smartphones owned by respondents has become so popular. First, with the penetration of smartphones with GPS capabilities, manufacture of dedicated GPS loggers has diminished rapidly and few such devices remain available on the market. Second, while in some countries such as Australia and New Zealand, the return of GPS devices is close to 100 percent, in other countries, like the USA, the return of devices is as low as 60-70 percent, which represents a major cost to any survey project. Third, it is relatively simple to have the GPS traces collected by smartphones transmitted in real time to a server, whereas the majority of dedicated GPS devices collect the data and store them on the device, so that the data can be retrieved only upon return of the device. Fourth, the cost of developing and then providing an app to smartphone owners is more cost effective than the cost of purchasing a sufficient number of dedicated GPS devices, sending these out to respondents, and retrieving them.

A key advantage of using a smartphone app is the ability to monitor transmittal of GPS data points in real time. Respondents who have forgotten to start the app can be sent a text message prompting them to do so. (This may also be a disadvantage in that it reminds respondents that their movements are being tracked in real time – a potential privacy issue.) The primary disadvantage of using a smartphone app has been the power consumption of the app, although recent developments have mitigated this problem to some extent. Initially, the apps would often drain the battery of the smartphone within a few hours. Currently, the apps may allow as much as 8 -10 hours of smartphone battery life, before the battery requires a recharge. Nevertheless, there is an increasing number of surveys that are using smartphones in preference to dedicated GPS devices, either for subsample surveys or for the entire survey.

To date, there have been two documented comparisons of the results of smartphones versus dedicated GPS devices. In the case of Montini et al. (2015), a very small sample of 33 respondents carried both a smartphone and a dedicated GPS device for a period of 8 weeks. In the case of Yu et al. (2015), a sample of 149 respondents participated in a technology demonstration study for a period of one week. Of the 149 respondents, 16 utilized both a smartphone app and dedicated GPS logger, and 58 respondents utilized a smartphone app, carried a dedicated GPS logger, and allowed their smartphone to be pinged to collect cell tower triangulation data. Both of these studies provided a very useful comparison of the capabilities of smartphones versus dedicated GPS devices. However, a comparative study in which some respondents use smartphones and some use dedicated GPS devices has not been documented to date, so that other comparisons, such as recruitment statistics for each type of GPS measurement, compliance rates, and other useful statistics have not been reported. In addition, the sample size in both cases was very small, so that it is difficult to be sure how generalizable these results are.

1.1. Reno-Sparks Region Study

The study for this paper was undertaken in Reno, Nevada, where a subsample of respondents were asked to undertake a one-week GPS study, with the original aim being for half of the subsample to use their own smartphones and half to use a dedicated wearable device. On the first day of the 1-week GPS period, each respondent in the subsample was also asked to complete a conventional diary. The data from both types of devices were then processed using the same software. It should be noted that this software was developed for GPS logger data specifically. In addition, a much larger subsample reported their travel only in the same diary that the GPS subsample used for the first day of the GPS study.

2. The Survey Protocol

2.1. The Survey Region

The survey region was the Reno-Sparks region, and unincorporated areas of Washoe County, Nevada. Reno is located close by Lake Tahoe, and is known as "The Biggest Little City in the World" (City of Reno, 2017). Reno is the largest city in Northern Nevada and is located in the southern part of Washoe County, nestled on the eastern slope of the Sierra Nevada Mountains in an area called the Truckee Meadows. Reno is famous for its hotels and casinos and as the birthplace of Harrah's Entertainment (now known as Caesars Entertainment Corporation) (Wikipedia, 2017). Reno is the most populous Nevada city outside of Clark County and the Las Vegas–Paradise, NV MSA Valley region, with an estimated population of 241,445 in 2015, (Wikipedia, 2017) and is the third most populous city in the state after Las Vegas and Henderson. Located just east of Reno is Sparks, Nevada. Sparks is also home to several hotels and casinos, and is known as being family friendly and for its parks and outdoor recreation destinations. It is also the home of the future Tesla Battery Gigafactory, which is under construction and is to be completed by the end of 2017.

2.2. The Survey Population

One objective of this study was to ensure the survey population was representative of all households residing in the Reno/Sparks MPO area. A stratified probability sampling approach was implemented for this project in order to ensure the resulting data was representative of all households in the Reno-Sparks MPO area. According to 2010 household and population data available from RTC, the survey universe comprised 158,489 households and 404,609 residents. The entire region was geographically divided into 20 planning districts, and stratified into four sociodemographic strata: household size, number of household workers, vehicle ownership, and household income.

2.3. Survey Design

A pilot survey was conducted from the beginning of June through the end of July 2015, and the main survey commenced in late August 2015, with final recruitment occurring in late January 2016. Only minor changes were made in procedures and instruments between the pilot and the main survey and results were combined from both the pilot and the main survey. The GPS subsample was designed as a random sample from three geographic areas within the Reno-Sparks metropolitan area, based on population density, with some oversampling in subareas to ensure sufficient representation of certain demographics in the sample. The aim was to obtain an equal sample of GPS logger and smartphone users. In both the pilot and the main survey, all household members age 12 and up were asked to carry the assigned GPS technology with them for the entire travel period of seven days. This posed a challenge in recruiting households with children under age 16, as many children in this age group do not own smartphones. In the main survey, the average number of calls required for GPS logger households was 2.02 calls per recruited household, with a range from 1 to 8 calls, while for the smartphone households, the average was 3.03 and with a range from 1 to 10 calls. Incentives were offered to households to induce participation. If households were recruited online, from the matched sample mailing, and completed the survey data online they were offered an incentive of $25 per household. In addition, households were offered a $25 incentive per person for returning the GPS devices with data, with a maximum of $75 per household ($100 if the household was recruited and retrieved online). Table 1 shows the recruitment statistics for the GPS and smartphone sample.

Table 1. Recruitment Statistics for the GPS Logger and Smartphone Samples.

Sample	Attempted	Recruited	Response Rate	Average Calls to Recruit
GPS Logger	11,688	333	2.9%	2.02
Smartphone	14,129	269	1.9%	3.03
Total	25,817	602	2.3%	2.49

As shown in Table 1, it required more calls per household to recruit households to undertake the smartphone survey than to undertake the GPS logger survey. The recruitment response rate for the diary only survey was 4.4%, so both the GPS and smartphone response rates were lower than the diary only response rate. All of the response rates are extremely low and seem to be symptomatic of transportation surveys in the USA at this time.

All respondents that were provided with GPS loggers and a portion of the respondents who were asked to use the smartphone app were provided with a Daily Record card. On this card, they were asked to report briefly what happened each day, with there being four primary options from which to choose. Those options were: “I took my GPS with me all day;" "I took the GPS with me for part of the day;" "Oops, I forgot to use my GPS device today;" and "I did not leave home all day." While experience has shown that people often do not use this Daily Record Card accurately, it does provide some helpful backup when data appear to be missing for a given day, or when there are more trips recorded in the diary than by the GPS device or smartphone.

3. Survey Results

Table 1 and the preceding section of this paper describe the recruitment process. In a GPS survey, there are several results that are important to investigate when performing the comparison of these two methods of obtaining GPS data. First, not all households comply with the request to record their travel either with the GPS logger, or with the app installed on their phones. Second, for the purposes of this survey, which was to use GPS data to compare with diary data and estimate factors to correct for the known underreporting of travel in diaries, it was necessary that people completed the diary on a day on which they also recorded their travel with GPS. In this survey, households were asked to use their GPS devices or smartphone app for one week, and were also requested to fill out their travel diary on the first day of the travel period for the GPS survey. Third, because respondents were instructed to carry their GPS devices or use their smartphone app for one week, it is useful to look at the number of days for which respondents by each GPS method actually utilized their GPS technology to record their travel. Fourth, it is useful to examine the trip rates produced from the data from each GPS method. In respect of this, it is important to discuss the methods used to estimate trips and their characteristics from the data. Before discussing those methods, it is also important, as a fifth and final issue, to determine how the number of trips reported in the diary compare to the number of trips recorded by the GPS device – whether logger or smartphone app.

3.1. Processing Methods

In this survey, it was decided from the outset to use the same processing software, irrespective of the source of the GPS data, with the exception of the first step in the procedures, where the smartphone data had to be conformed to a similar format as the GPS logger data. In both cases, the software used was a proprietary package of software tools developed by the University of Sydney over the past decade (Stopher et al., 2011), called G-TO-MAP. As noted earlier, this software was developed to be used with GPS logger data specifically. A brief summary of the process is provided in this paper and is shown in Figure 1.

The first step in the process is to assemble the downloaded data, which are grouped into batches of approximately 10 households for computational efficiency. In addition, deployment data (the start date for GPS recording for each household) is added. The next step is to convert the GPS data stream to the format expected by the G-TO-MAP software. The software uses the number of satellites in view and the Horizontal Dilution of Precision (HDOP) to determine if data points are valid. The HDOP data items are not collected in the data stream from the smartphone app used for this project, however these data items can be interpolated from the accuracy measure that the app records. G-TO-MAP requires the HDOP data items. Table 2 shows how these values are interpolated from the 'accuracy' recorded by the Smartphone. These values would generally mean that data points recorded by the app as having an accuracy of greater than 100 meters would be rejected as invalid, while all others would be considered to be valid. G-TO-MAP then checks the data for validity. A common problem with all GPS devices (smartphone or dedicated GPS device) is that there are occasional roll-backs in time of a few seconds in duration. These cause serious problems in the processing and so must be detected and corrected before the processing continues. Typically, roll-backs in time are on the order of 3 to 14 seconds, although occasionally a larger value may be encountered. GPS experts are unable to explain why this happens, but it is commonly found in any GPS data stream.

After the data have been checked for validity and any necessary corrections made, the data are then processed through a step called trip identification. This step uses a user-provided number of seconds to define the stop duration that is to define the end of a trip. In this project, a duration of 45 seconds was used to define the end of a trip, because it has been found that this provides close to optimal results in terms of a trade-off between the need to link through stops that are not real destinations, and the need to split trips where a short stop (such as a pick up or drop off) occurs. This step provides a preliminary trip table which is subjected to some validation tests, to ensure that such things as bus stops and train stations are correctly picked up, and then the initial trip list is output, together with first draft

Google Earth maps. The trip list is now input to a link matching process that uses information on the road network, public transport networks, bus stop and train station locations, and other relevant network information.

Table 2. Interpolation of HDOP and Satellites in View from the Accuracy Measure.

Smartphone Accuracy Measure	HDOP	Satellites in View
>100 meters	10	2
10.1-100 meters	5	3
5.1-10 meters	3	4
≤ 5 meters	1.5	6

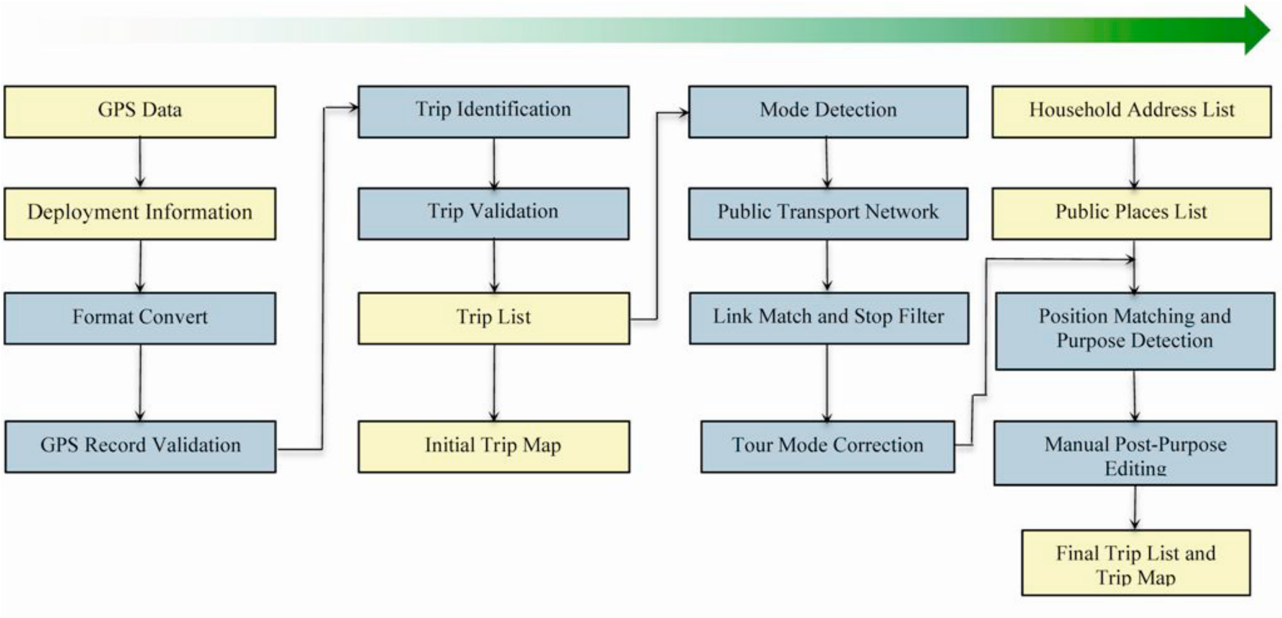

Fig. 1: Schematic of the GPS Processing Software

This processing step provides a preliminary identification of mode, based on proximity of the path to the various networks, household ownership of bicycles, speed, acceleration, and other information to identify the probable mode of travel. The first mode to be identified is walk, because it is slowest, may not adhere to the networks, and has the lowest rates of acceleration and deceleration. Following this, public transport is identified, based on speed, acceleration, deceleration, and proximity to the public transportation networks. The remaining trips are then allocated to car and bicycle, although a check is made on bicycle ownership to determine if bicycle is likely. The home location is also used in this step to identify tours, which are defined as any sequence of trips that begins at home and eventually ends at home.

The output from this step is a trip list with mode identified, which is then processed by a step called "tour mode correction". In this step, the sequence of mode use on a tour is determined and checked against a set of rules as to what sequences of mode use are considered possible. For example, a sequence such as car-car-bus-bicycle would be considered improbable, because one normally must return home with the car with which one left at the beginning of the tour. Therefore, the bus and bicycle legs would be changed to car. After these checks are made and corrections made to the mode identification, the data are fed to the final step of purpose identification. In this step, additional information is input on school, shop, and work locations, and purpose is imputed from the geographic information on shops, schools, work, and home, and from the duration of time spent at the destination location.

At this point, a manual step is introduced, called "post-purpose editing", in which a trained editor examines each trip and the information on mode and purpose, using both the trip list and the Google Earth maps. An examination may be made of the street view at the destination of the trip to determine if it is consistent with the imputed purpose. Also, each destination is checked to make sure it is a real destination, and not a traffic stop. The editing typically involves joining some trips together through traffic stops, splitting some trips to pick up very short stops, changing mode and changing purpose, where appropriate. A set of rules is used to guide the editing process, so that it is done objectively. The output at the end of this step is a final trip table from the GPS data, providing day, date, time start, time end, origin (with latitude and longitude), destination (also with latitude and longitude), duration of travel in time and distance, imputed mode, imputed purpose, and number of people travelling together. Subsequently, data from the Daily Record cards is added to each trip, indicating whether or not the respondent used the GPS device on each day. Any missed days in the middle or ends of the record are added, when possible, based on the Daily Record data, which may indicate certain days on which the person did not travel.

3.2. Compliance Results

The recruitment goal was to have an equal number of households recruited for each type of GPS technology. As shown in Table 3, including the pilot sample, the goal was to recruit 782 households, split equally. However, in actuality, only 77 percent of this goal was achieved and the smartphone and GPS logger split was not equal. As was found in both the pilot and the main survey, recruiting households to use the loggers was more successful than recruiting them to use their own smartphones. It should be noted that not all households that were selected to participate via smartphone had smartphones available for all household members age 12 and up, so they were converted to diary-only. Not everyone was comfortable using their smartphone for the survey – an attitude that will likely change with the rise in the prevalence of surveys like this. Of the recruited households, 200 (60%) that were recruited to use the GPS loggers actually complied with the request and returned loggers with useable data. For the smartphone app, the actual compliance was 112 (42%) of the recruited households. These results indicate households are more willing to comply with use of GPS loggers than smartphones.

Table 3. Recruitment, Completion and Results by GPS Household Type.

Sample Type	Recruit Goal	Recruit Total	Recruit Percent Complete	Retrieval Goal	GPS/ Smartphone Complete	GPS/Smartphone plus Diary Complete	Percent Complete Goal
GPS	391	333	85%	250	200	158	63%
Smartphone	391	269	69%	250	112	67	27%
Total	782	602	77%	500	312	225	45%

To be useful for the factoring exercise, households and the individuals within those households needed to complete their travel diaries on the start day of their GPS logger or smartphone app travel period. Table 4 shows the details of how respondent households were lost from those that completed GPS data.

Table 4. Reasons for Loss of Households from the Compliant Sample.

Sample Type	GPS/ Smartphone Complete	Diaries Not Completed	GPS not used on Diary Day	GPS/Smartphone plus Diary Complete
GPS Logger	200	23	12%	19
Smartphone	112	21	19%	24
Total	312	44	14%	43

In addition to the losses shown in Table 4, 6 individuals in households that included some full respondents, did not complete diaries. Also of note, 19 individuals in households that included some full respondents did not use their GPS logger or the smartphone app on the diary day; 5 individuals did not use their smartphone on the diary day, and 14 did not use their GPS loggers. (It should be noted that we have included among the counts of complying households those households that reported no travel on the diary day.) In total, this provided 345 persons in 225 households who could be used in the comparison between diaries and GPS traces. It is noteworthy that the compliance rate for smartphone households was lower than for GPS logger households, so that the final percentages of useable households for the factoring are 63 percent for the GPS logger and 27 percent for the smartphone.

3.3. Matching Results

Fourteen respondents reported both in the diary and the Daily Record that they did not travel on the diary day. All 14 used GPS loggers. This reduces the number of individuals available for matching on actual travel to 331, but also shows a good match on no travel days. These outcomes affect 11 households. A further 30 individuals recorded trips either in the diary with no GPS trips (14, one of whom was a smartphone user and 13 of whom used GPS loggers) or on the GPS with no diary trips (16, 3 of whom were smartphone users and 13 of whom were GPS logger users). These are more troublesome and indicate a problem, possibly that they completed the diary for a different day from the one requested, or that the GPS was not carried on the diary day. In 12 of these cases, the respondent had filled in their Daily Record Card to show that they carried their GPS with them all day on that day: in 5 cases, the respondent had no GPS trips, but reported diary trips; in the other 7 cases, the respondent had GPS trips recorded but indicated no travel in the diary. The numbers of trips recorded by GPS for the 16 persons whose diaries claimed no travel totaled 98, and varied from 2 to 17 trips. For the 14 persons who claimed on the GPS daily record not to have traveled on the diary day, there were 57 trips recorded in the diaries, ranging from 1 to 8 trips. Figures 2 and 3 show the comparison of the trip frequency for those respondents who had matching data (including no travel days) between the Diary and the GPS. The GPS captured a total of 1,840 trips compared to the 1,679 in the diaries.

Table 5 shows the results in terms of matching of trips and shows a far poorer picture of diary reporting than Figures 2 and 3. In the GPS record, some start and end times are missing, where editing has interpolated a trip. Therefore, the correct count of trips that are only in the diary is that of the origins and destinations that are only in the diary, i.e., 425 trips. On the other hand, there are 586 trips that are in the GPS records only and not in the diaries. This latter suggests an under-reporting rate of 35 percent, based on the number of diary trips actually recorded (including the 425 that were not recorded by the GPS). As indicated in Table 5, some trips show a complete match, at least within the tolerance limits permitted in this project. However, Table 5 also indicates that there are 276 trips that are recorded in the diary only and 383 that are recorded by the GPS only. The former will occur most probably if the GPS is left at home, or if the trip is very short, so that the GPS is unable to get a fix on position. The latter will occur when people forget to enter trips they have made into the diary, or intentionally omit them because of fatigue in answering, or forget that they have made the trips at all. From a comparison of the GPS and smartphone results from the match, it appears that there is little difference in the ability of the two methods to detect matching trips, non-matching trips, diary only trips, and GPS only trips. The GPS logger shows more no travel days, primarily because the Daily Record Card was not provided to all smartphone users.

Table 5: Status of Matches between Diary and GPS

Match Status	Origin			Destination			Start Time			End Time		
	GPS	SP	TOTAL	GPS	SP	TOTAL	GPS	SP	TOTAL	GPS	SP	TOTAL
Matched	630	396	1026	573	346	919	617	358	975	535	300	835
No Match	136	77	213	193	127	320	130	97	227	212	155	367
Diary Only	148	128	276	148	128	276	167	146	313	167	146	313
GPS Only	229	154	383	229	154	383	224	152	376	224	152	376
No Travel	14	0	14	14	0	14	19	2	21	19	2	21
TOTAL	1157	755	1912	1157	755	1912	1157	755	1912	1157	755	1912

There are 23 respondents where nothing matches between the diary record and the GPS record; 3 of these respondents used the smartphone app and the remaining 20 used GPS loggers. For these respondents, no origins or destinations match, no times match, and generally mode and purpose do not match either. These are the most puzzling cases. There are a further three cases, (1 for the smartphone and 2 for the GPS logger), where the origins and destinations do not match, but some or all of the times match. These 26 respondents recorded 129 trips on their GPS devices and 97 trips in their diaries. Two explanations for this situation are possible. On the one hand, the respondents could have handed their GPS devices to another person on the diary day and that is the travel that was recorded, while the respondent filled out the diary for what he or she actually did on the day. The other possibility is that the person filled out the diary for a different day from that for which he or she was instructed to use the diary.

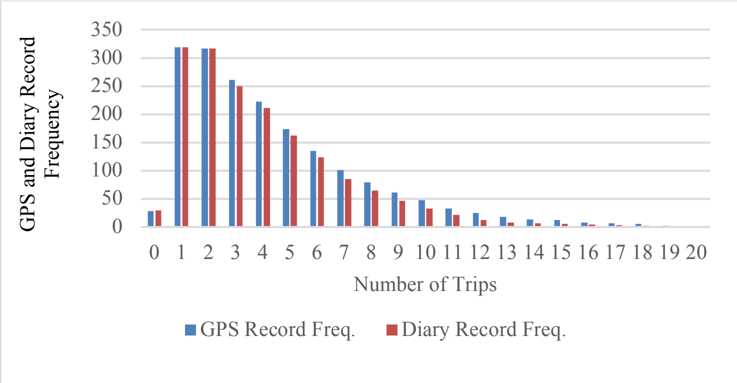

Fig. 2: Trip Frequencies for the Matched GPS Sample (Diary and GPS)

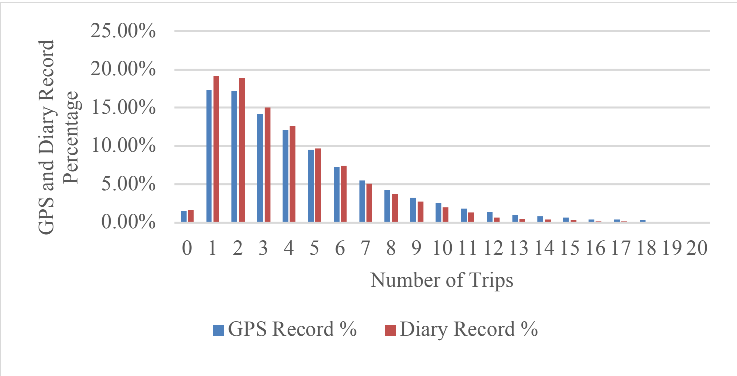

Fig. 3: Trip Frequency Percentages for the Matched GPS Sample (Diary and GPS)

It is noteworthy, however, that 15 households (whose data are not included in these statistics) completed their diaries apparently for a date that was 6 or more days before the beginning of the GPS period, or after the end of the GPS period. It is quite plausible that some respondents may have completed their diaries for a different date from the one on which they were expected to complete them, without approval from the survey team.

Overall, one can conclude from the matching exercise that the GPS logger and the smartphone app produce similar results in terms of proportion of trips that show a good match to diary data, as well as the proportion of trips that do not match, or that are recorded only in the GPS, or only in the diary. There is, however, a much greater likelihood of a GPS logger recording data that are totally mismatched to the diary than the smartphone, possibly because smartphones are unlikely to be switched between people, whereas this is not the case for GPS loggers.

3.4. Trip Rates and Demographics

The final comparison made in this study is between the trip rates, and then a comparison is made of the demographics of the samples. For the GPS logger sample, the average per person daily trip rate was 4.45 in the diaries and 4.97 from the GPS loggers. For the smartphone app, the figures were 5.76 in the diaries and 6.06 in the GPS data. It is interesting to note that the figures for the smartphone app are substantially higher in both cases to those for the GPS logger. However, the diary under-reporting rate for the GPS logger is 11.7 percent, compared to 5.2 percent for the smartphone app. These differences require some further exploration. It is also important to note that the trip rate for those over the age of 12 who did not use GPS is 3.80 trips per person per travel day, which is markedly lower than the rates for either the GPS logger subsample or the smartphone app subsample.

Table 6 shows the breakdown of household size, operating vehicles, and bicycles for the GPS households, the smartphone households, the total of the GPS sample, ns the diary only sample. From Table 6, it is apparent that the two samples – GPS and smartphone – are not identical on any of these four demographic characteristics. Indeed, it appears that the smartphone households were larger, owned more operating vehicles, also owned substantially more bicycles, and tended to be higher income than the GPS logger households. The higher car ownership and bicycle ownership, together with the higher incomes could well account for the higher trip rates (diary and GPS) for the smartphone sample, compared to the GPS sample. The GPS logger households are also not the same as the diary-only households, with fewer 1-person households, fewer zero car-owning households, fewer non-bicycle households, and higher income.

4. Conclusions

Further to the results reported in Montini et al. (2015), where it was concluded that the results of using a smartphone app and a dedicated GPS logger are not the same, this study has pointed to some more important conclusions. First, it is apparent that it is generally harder to persuade potential respondents to use their smartphones for tracing their travel, than to get them to use a dedicated GPS device that is furnished to them for the duration of the study. The recruitment rate for GPS loggers was more than 50 percent higher than for smartphones. Second, the compliance rate was higher by those households recruited to use GPS loggers than those asked to use a smartphone app on their own smartphone.

Looking at the final compliance of households that provided both completed diaries and GPS records for the same day, the rate for GPS loggers is more than twice that of the smartphone households. Therefore, simply in terms of the recruitment and compliance of households, the GPS logger is preferable to the smartphone app. The primary explanation given by selected households for refusing to participate using the smartphone technology was they were concerned that downloading the smartphone app would provide a two-way portal to the personal data stored on their smartphones. The technology is too new for participants to research to find out that this is not possible with the app used for this particular study. The secondary explanation provided was that household members age 12 and up did not all own smartphones, therefore were not able to participate utilizing the smartphone technology.

Third, in terms of the rate of matching between the diary and GPS records, there is little difference between the smartphone and the GPS logger, using identical processing software to identify trips and their attributes. However, there was found to be a substantial difference in trip rates and in the estimation of diary underreporting for the smartphone sample compared to the GPS logger sample. The smartphone respondents appeared to underreport by about half the rate that was found from the GPS logger. There was also found to be a significant difference between the demographics of the households that agreed to use their smartphones for the traces, compared to the GPS loggers. smartphone households were found to be larger in size, own more vehicles and bicycles, and to have higher incomes than the GPS logger sample, whereas the GPS logger households were found to be smaller in size, own less vehicles and bicycles, and to have lower incomes than the smartphone sample. This suggests that there may be a bias in any sample that attempts to use smartphones only or GPS loggers only, for measuring travel.

Table 6: Comparison of Household Size, Operating Vehicles, Bicycles, and Income

Attribute	Value	Diary Only	Subsample					
			GPS		RS		Total	
HHSize	1	32%	28	12%	8	8%	36	11%
	2	45%	115	49%	43	41%	158	47%
	3	12%	47	20%	23	22%	70	21%
	4	8%	39	17%	20	19%	59	17%
	5	2%	5	2%	10	10%	15	4%
	6	1%	1	1%	1	1%	2	1%
Vehicles	0	6%	10	4%	2	2%	12	4%
	1	35%	71	30%	18	17%	89	26%
	2	44%	115	49%	62	59%	177	52%
	3	11%	34	15%	17	16%	51	15%
	4+	4%	5	2%	6	6%	11	3%
Bicycles	0	48%	90	38%	21	20%	111	33%
	1	17%	40	17%	17	16%	57	17%
	2	19%	64	27%	14	13%	78	23%
	3	6%	20	9%	17	16%	37	11%
	4	6%	16	7%	14	13%	30	9%
	5+	5%	5	2%	22	21%	27	8%
Income	<$10,000	4%	5	2%	0	0%	5	2%
	$10-24,999	12%	21	9%	11	11%	32	9%
	$25-34,999	9%	19	8%	4	4%	23	7%
	$35-49,999	12%	34	15%	13	12%	47	14%
	$50-74,999	18%	59	25%	15	14%	74	22%
	$75-99,999	13%	24	10%	13	12%	37	11%
	$100-149,999	13%	41	17%	26	25%	67	20%
	$150-199,999	4%	13	6%	10	10%	23	7%
	$200-249,999	1%	3	1%	2	2%	5	2%
	$250,000+	2%	8	3%	11	11%	19	6%
	Don't Know	2%	3	1%	0	0%	3	1%
	Refused	9%	5	2.1%	0	0.0%	5	2%

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