Activity diary surveys using GPS mobile phones and PDA

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Abstract: Activity diary is necessary information for investigating the relationships between individual travel behavior and activity engagement. A GPS mobile-phone-based activity diary survey system and a GPS-equipped PDA-based activity diary survey system are developed in this study. The software programmed in Java works on mobile phone devices for entering information on activity diaries. Positional data are automatically collected at regular intervals by GPS-equipped mobile phones. Two pilot surveys were conducted for a total of 49 participants to examine the advantages of the survey system. By comparing activity data collected by the software with data collected by the conventional paper-based activity diary survey, it was found that the system was useful for reducing a "time lag" in data entry and mitigating spatial constraints for data entry. However, the respondent's burden depends on the characteristics of the respondents. The software for the GPS-equipped PDA-based activity diary survey is programmed in HTML. Two pilot surveys were conducted and activity data collected by the PDA were compared with paper-based survey data. Both the number of activities and total activity time recorded were longer in the paper-based survey, especially in in-home activities. It could be difficult for the respondents to record parallel activities because of the pre-programmed check system in the PDA software.

INTRODUCTION

Travel is considered a demand, derived from the desire to engage in activities at certain locations. Hence, activity diary data are necessary information to analyze individual activity-travel patterns and to investigate the relationships between individual travel behavior and activity engagement. Recently, the importance and effectiveness of activity diary data have been recognized for evaluating the effects of policy options on individual quality of life in urban space and time. The most common survey method of collecting activity diary data has been a paper-and-pencil interviewing (PAPI). Respondents are asked to fill in paper-based activity diary questionnaire sheets for a day or over a period of time (two days, one week, etc.). However, there are several problems with this traditional survey method. First, because of the great amount of time it takes for respondents to fill in the activity diary sheet, the respondents' burden is considerably large to record all of the activities in the questionnaire survey sheet. Since most respondents tend to record the activities engaged in for the survey day after coming back home at night, data accuracy about the activity type, start/end time and location, depends mostly on their memory retention. As for the surveyors, it takes considerable time and money for distributing and collecting survey materials and for editing and inputting collected data. For the innovation of survey methods for activity data collection, a lot of researchers are trying to reinvestigate the existing technologies and to develop new survey methods (*1*).

In recent years, people can make decisions on activity scheduling and travel behavior more dynamically than before, by acquiring both pre-trip and en-route information on transport systems and activity opportunities from various media. Consequently, not only revealed activity-travel patterns but also activity scheduling processes have been of interest to transportation researchers. Some researchers have been doing research on the development of computer software for collecting data on activity patterns and scheduling processes, e.g. CHASE (*2*) and React! (*3*). CHASE and React! are computer-assisted self-interviewing (CASI) systems working on a PC. Personal digital assistants (PDA) and mobile phones can also be used as a device for data collection (*4−5*). On the other hand, the use of telecommunications such as mobile phones, e-mail and the Internet, affects individual travel behavior. To analyze interaction between telecommunications and activity-travel scheduling/patterns, information on both activity diaries and the use of telecommunications are required. However, methods applied to collecting effectively such data remain uninvestigated. Recently, in the field of activity-travel surveys, positioning technologies such as global positioning system (GPS) and global system for mobile communications (GSM) have been widely applied to collecting detailed information on travel trajectory. The technologies make it possible to automatically collect information about position (longitude and latitude) and time (and speed for GPS) at a specific interval. To collect positional data using GPS and GSM, respondents are required only to carry the device. There has been a lot of research on travel data collection using GPS and GSM (e.g., *6−10*). GPS can be attached to PDA and recently is installed inside the mobile phone device (see *11*). PDA and mobile phones have also been used for data collection as CASI in a wide variety of survey fields. Especially, most of the younger people are routinely using mobile phones for voice and e-mail communications, and they have less difficulty in operating the devices than elder people. Investigating possibilities of the survey system combined positioning technologies and mobile devices for activity diary data collection could be important in terms of mitigating the problems in activity diary surveys.

The objectives of this study are to develop a GPS mobile-phone-based activity diary

survey system and a GPS-equipped PDA-based activity diary survey system, and to examine their advantages and disadvantages over conventional paper-based activity diary surveys.

DEVELOPMENT OF A GPS MOBILE PHONE AND PDA-BASED ACTIVITY DIARY SURVEY SYSTEMS

Selection of the System Platform for Data Collection

The requirements of the survey system in this study are as follows:
- to directly collect electronic data on activity diaries and to transmit the data through a wireless network (GSM network and the Internet);
- to use a mobile device which people can easily carry in their daily lives, so that they can enter information on activity diary into the device at anytime and anyplace without spatial and temporal constraints;
- to automatically collect positional data at a regular time interval to specify activity locations and travel routes; and
- to reduce the survey cost of time and money both for distribution and collection of survey materials, and for transmitting, editing and inputting the collected data.

Table 1 summarizes comparison among system development platforms. Mobile phones, PDA and laptop PC are possible options of mobile electronic devices for data collection. The monetary cost for data transmission from the device to the surveyor (or a dedicated server) is cheaper for a laptop PC with Internet access than mobile phones and PDA with a mobile connection. The laptop PC is the best for respondents to enter activity information in terms of the size of monitor display. However, it would be less convenient for respondents both to carry and to enter activity information at anytime and anyplace. Mobile phone and PDA are smaller devices and easier to be carried. The mobile phone has a smaller monitor and less flexibility for the design of data entry form than PDA, but the number of mobile phone users is much larger than that of PDA users in Japan – the number of subscribers is about 90 million for mobile phones, but the number of PDA users would be less than 10 million. From the above reasons, we applied mobile phones and PDA for the platform of system development.

TABLE 1 Comparison among Devices for Activity Diary Data Collection

	Mobile phone	PDA	Laptop PC
Monetary cost for data transmission	High	dependent on attached media	Low
Size of monitor display	Small	Medium	Large
Easiness to be carried	Easy	Medium	Difficult
Spatial constraints for data entering	Low	Low	High
Flexibility for the design of data entry form	Low	Medium	High
The dissemination in people	High	Low	High

Development of GPS Mobile-Phone-Based Data Collection System

There are four mobile phone carriers in Japan; NTT DoCoMo, Inc., KDDI Corporation, TU-KA

Cellular Inc. and Vodaphone K. K. At the time this research was launched into, the only carrier that provided mobile phone devices with GPS installed was "*au*" by KDDI Corporation. The "*au*" employs "gpsOne" which is called the Assisted GPS (see *12*). It calculates the current position using not only GPS but also information on received signals from multiple base stations to which the mobile phone device is connected. Therefore, positional data can be collected even if GPS was not available because of obstructed views of GPS satellites (e.g. inside buildings, at underground stations, etc.) or carried in a coat or jacket pocket. Furthermore, end users can develop original Java applications working on the "*au*" mobile phone device and distribute it without getting permission from KDDI Corporation. Therefore, we employed the "*au*" mobile phone system among the four carriers.

We developed software in the Java language so that respondents can download the software via the Web and install it on their own mobile phones. This freed the surveyor from having to contact the respondents to distribute the software. Also the respondents did not need to carry two mobile phone devices; one for the survey and another for their own use. When starting the software, information on position specified by GPS and ID number is transmitted automatically to a dedicated server at regular time intervals and stored. The time interval can be set in the JAVA program source file arbitrarily. For entering information on an activity diary (activity type, start/end time, location, travel mode and accompanied persons) and telephone-use diary (time, media, partner, send/receive and the contents for communications), a data entry form was programmed as shown in Figure 1.

Respondents enter start/end time directly by pushing dial buttons (see Figure 1). Information on the activity type, location, travel mode and accompanied persons is selected from the predefined list. If an appropriate alternative does not exist in the predefined list, respondents directly enter their response in the blank cell. As soon as the respondent finishes entering information on an activity, the time is also automatically recorded to analyze the "time lag" between activity implementation and activity recording. The end time of the previous activity is automatically set as the start time of the next activity. Error checking functions test the validity of the start/end time (e.g. whether the characters are number and between 3:00 to 27:00 (3:00 a.m. on the following day), whether the start time is earlier than the end time). When the entered information is not correct, it displays a warning message. Respondents can confirm the entered information at anytime, and they can modify the data if they found some mistakes. The diary data is temporarily stored in the mobile phone. When the capacity of the mobile phone's built-in memory becomes full, by pushing two buttons, the data is transmitted via e-mail to the surveyor's e-mail address. The surveyor can identify the data by accessing the server computer through the Internet in real time.

Since positional data are transmitted only while the software is running, respondents must always keep the software running during the survey period. When the respondents use their own mobile phone for the survey, they can receive phone calls and e-mails while the software is running. However, they need to end the software to make phone calls and send e-mails, and restart the software after finishing it. When the battery level goes below a specific level, the software automatically exits. This function can avoid data deletion stored in the mobile phone device if power suddenly runs out.

The 1st survey was conducted using this software as described in the next chapter. After the 1st survey, we improved the software for some functions. The 1st version of the software required respondents to select one activity type from 16 alternatives (sleep, personal care, meals, work, study, housework, school/classes, research, TV watching, the Internet, hobbies, sports,

social activities, shopping, resting, and travel) or enter the name of activity only when select "others", whereas in the 2nd version, the name of a concrete activity type was entered directly from dial buttons. Activity data were transmitted by HTTP in the 2nd version, so respondents' operation to send data became easier (pushing one button). In the 1st version, the surveyor needed to manually combine the activity data of each respondent sent by e-mail, because the respondent must send the data two or three times a day. Whereas, in the 2nd version, transmitted data are automatically added to one data file in the server computer.

FIGURE 1 Snapshot of Data Entry Screen in the 1st Version of the GPS mobile-phone-based System

Activity Diary Survey Using the GPS Mobile Phone Device

To examine the advantages and disadvantages of the GPS mobile-phone-based activity diary survey over the conventional paper-based activity diary survey, two pilot surveys were conducted in January and April 2004 with a total of 49 participants living in Tokyo.

As the 1st survey, in January 2004, two-day activity diaries were collected. The number of the respondents of the survey was 36. Thirty three of them were 20's years old and 3 of them were 30's. Thirty one respondents were males. All the respondents were daily using a mobile phone. The average length of time of mobile phone use was 4.9 years. The respondents were asked to start the software when they woke up and to exit it when they went to sleep in order to save GPS tracking costs. They were asked to record activity diaries both in the mobile phone software and in the conventional paper-based questionnaire sheet on the same day. For the paper-based survey sheet, they were also required to record the date and time when they recorded activities in the survey sheet. This information was used for an analysis of the "time lag" between the activity end time and the data entry time. A total of 6 respondents were daily using

an "*au*" mobile phone on which the survey software was able to work (type A5xxx or W1x). They were asked to use their own mobile phone and to download the survey software from the survey website ("*au*-users" in this study). Then, a survey manual and a paper-based questionnaire sheet were mailed to them. The "*au*-users" were not contacted by the surveyor face-to-face. On the other hand, the "*au*" mobile phone (type A5402) with pre-installed survey software was provided to the respondents who were not using "*au*" mobile phones ("non-*au*-users"). The "non-*au*-users" were asked to carry it in addition to the mobile phone they were personally using. They were instructed by the surveyor how to use the device face-to-face. On the 1st day, the respondents were asked to record their activity diary, whereas on the 2nd day, they were asked to record not only their activity diary but also their telephone use diary.

The 2nd survey was conducted using the 2nd version of the system in April 2004 for 13 participants who were all graduate students in The University of Tokyo. This survey was also a trial to collect activity diary data by mobile phones as an input to a GIS-based activity-travel simulator, SMAP-E (*13*). All the 13 respondents were "non-*au*-users," so the "*au*" mobile phone which the surveyor prepared was provided to them during the survey period. The respondents were asked to record activity diaries in the mobile phone for three days and in the paper-based questionnaire sheet for the remaining four days. Telephone use diaries were not recorded in the 2nd survey.

The time interval of GPS tracking was set at 10 minutes. Batteries can keep the mobile phone working for 5 to 6 hours in this setting. It took about 900 yen for one day data collection for one respondent, including costs for both transmitting the data and GPS tracking. After the diary survey, the respondents were asked to answer some questions regarding comparison between the mobile phone-based survey and the paper-based survey.

Comparison of Diary Data between Mobile Phone Survey and Paper-Based Survey

Data Handling Time of the Surveyor
Data handling time to complete an electronic database was much less in the mobile phone survey than in the paper-based survey. In the 1st survey, it took about 3 minutes at minimum for the surveyor to input two-day activity diary data of one respondent, from the paper-based survey sheet into a Microsoft Excel sheet. Whereas, it took only 30 seconds to combine two-day activity diary data sent by e-mail from the mobile phone device and to make an Excel sheet for one respondent. It was found that time required for editing and inputting the data was considerably reduced in the mobile phone survey, comparing with the conventional paper-based activity diary survey. In the 2nd survey, the respondents themselves input four-day activity diaries from the paper-based survey sheet into an Excel sheet. The instructor of the graduate course managed the data handling of three-day activity diary data collected by the mobile phone system and sent the data to the respondents.

Characteristics of the recorded data
In the 1st survey, the average number of the recorded activities in the mobile phone was 15.0/day and that of trips was 2.8/day. There was not a significant difference in the number of recorded activities and trips between the mobile phone and the paper-based diary. However, there were some problems in the data collected by the mobile phone such as:
- two consecutive activities overlapped in timing;
- existence of blank time period; and

- several in-home activities not recorded.

A total of 69 activities recorded in the paper-based diary were not recorded in the mobile phone. Twenty-seven of them were "sleep" activities. For the remaining 42 activities, 24 of them were in-home activities and 21 of them were activities engaged at midnight. On the other hand, a total of 35 activities recorded in the mobile phone were not recorded in the paper-based diary. Most of the activities were relatively short-time activities. In the 2nd survey, the average number of the recorded activities in the mobile phone was 12.1/day and that of trips was 3.7/day.

Frequency of Data Entry

Frequencies that the respondents entered information on activities were compared between the mobile phone and the paper-based diary. In the 1st survey, the average number for the paper-based diary was 2.1/day and that for the mobile phone was 8.1/day. There was no respondent who recorded data more frequently in the paper-based diary than in the mobile phone. This means the respondents recorded activities more frequently in the mobile phone than in the paper-based diary. This could be due to the higher flexibility in space and time for recording data in the mobile phone survey. In the 2nd survey, the average number of the frequency of data entry was 3.7/day for the mobile phone. The respondents were not required to record data entry time for the paper-based diary in the 2nd survey.

"Time Lag" between Activity Implementation and Data Entry

Figure 2 shows cumulative distribution of a "time lag" from the end time of an activity (activity implementation) and the time when the activity was recorded. For example, if an activity end time was 10:00 a.m. and the activity was recorded at 10:30 a.m., the "time lag" is 30 minutes. If an activity was recorded before the activity end time, the "time lag" becomes a negative value. As shown in the figure, the "time lag" was shortest in the mobile phone of the 1st survey and largest in the paper-based diary of the 1st survey. The averages of the mobile phone of the 1st survey, mobile phone of the 2nd survey and paper-based diary of the 1st survey were 87 minutes, 179 minutes and 445 minutes, respectively. In the mobile phone of the 1st survey, 39.6% of the total activities were recorded within 5 minutes of the activity implementation, whereas 26.6% of the total activities were recorded after 600 minutes (10 hours) in the paper-based diary of the 1st survey. The higher frequency and shorter "time lag" suggest that respondents can enter activity information into the mobile phone software at anytime and anyplace, and from clearer memory, so data accuracy could be higher than the traditional paper-based survey. An intriguing result is that about 10% of the activities in the mobile phone of the 1st and 2nd surveys were recorded before the activity was finished. But in terms of inter-personal variability, the average, minimum, maximum of each respondent's average "time lag" were 105 minutes, -12 minutes and 895 minutes, respectively, and the standard deviation of all the respondents' average "time lag" was 153 minutes. Thus, the "time lag" was much dependent on individuals. In the 2nd survey, the average, minimum, maximum of each respondent's average "time lag" were 200 minutes, 13 minutes and 524 minutes, respectively. The difference of "time lag" between the mobile phone diaries of the 1st and 2nd surveys could be due to the difference in survey method, software and respondents, but we cannot know the specific reason from this study.
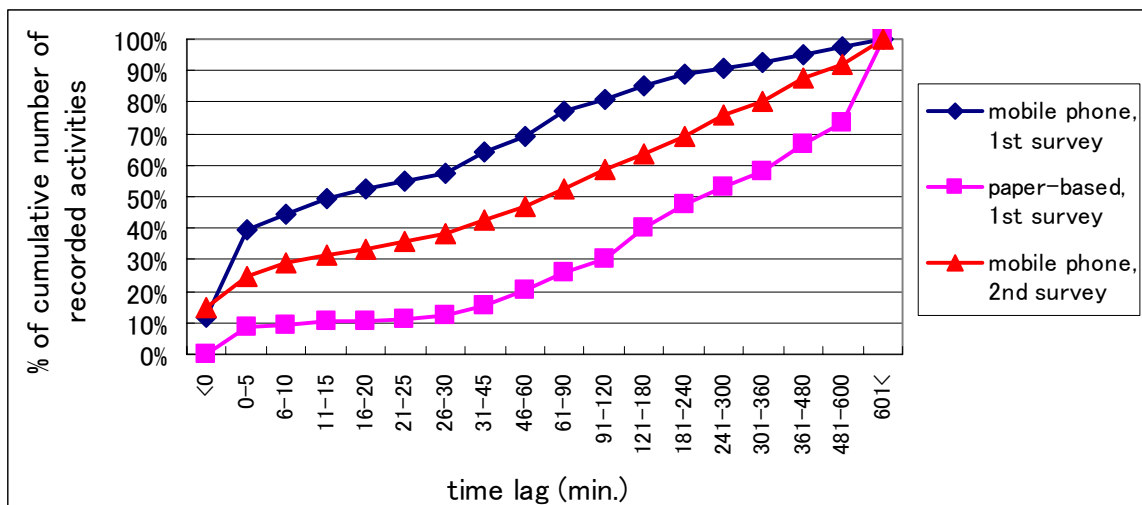
FIGURE 2 Time Lag between Activity Implementation and Data Entry

Locations Where Data Were Recorded

As shown is Figure 3, in terms of locations where activities were recorded, in the paper-based diary of the 1st survey, 67% of the activities were recorded in their home and 32% were in their work or school places. Only 1% of the activities in the paper-based diary were recorded while traveling. On the other hand, 47% of activities in the mobile phone of the 1st survey were recorded in their home, 22% were in their work or school place and 11% were in other locations. About 20% of the activities were recorded while traveling, of which, 10% was traveling by train, 5% was walking and 1.5% was while riding a bicycle. In the mobile phone of the 2nd survey, 35% of the activities were recorded in their home, 35% were in their school place and 20% were in other locations. 35% were recorded while traveling of which 21% were traveling by train, 7.5% were walking and 2% were while riding bicycle. The results show that the mobile phone makes it possible for the respondents to enter activity diary information without spatial and temporal constraints.
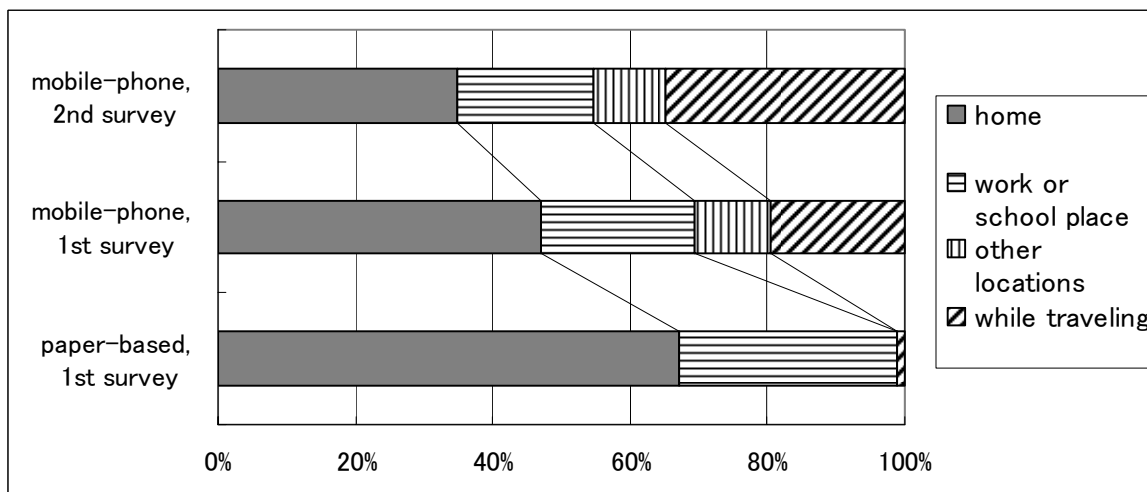

FIGURE 3 Locations Where Data Were Recorded

Respondents' Preference in Different Survey Methods

This section presents the analysis of the respondents' answers to questions about the survey methods after the activity diary survey was finished.

Impacts of the Mobile Phone Survey on the Respondents' Behavior
Three respondents in the 1st survey were conscious of being positioned automatically by GPS, for example, they answered that "I didn't engage in activities which I didn't want to be known," and "I did activity-travel patterns as easy as I can record them." Fifteen of them answered that their activity-travel behavior and mobile phone use were at least affected by participating in the survey. For example, some respondents took into consideration the battery capacity of the mobile phone device, so they did not travel further than usual from their home and office or school. For the participants who used their own mobile phone, since they had to stop the system to make a phone call or to send an e-mail, they communicated less with the mobile phone than normal usage. Automatic positioning and battery problems could cause a little different activity-travel behavior from the normal pattern.

Perceived Time to Complete Data Entry
To investigate the respondents' burden, the respondents were asked which survey method, mobile phone or paper-based diary, took longer time to complete data entry of the activity diary. Table 2 shows the result. For the "non-*au*-users" of the 1st survey, although 30% of the respondents answered that it took shorter time in the mobile phone to complete data entry, 40% of them felt that it took longer time in the mobile phone survey. It was found that the respondents' burden would depend on each respondent's characteristic and her/his literacy of mobile phone use. For the 2nd survey which required recording telephone use diaries, more respondents answered it took longer time in the mobile phone.

TABLE 2 Respondents' Perceived Time to Complete Data Entry (the Number of the Respondents)

	"non-*au*-users"		"*au*-users"	
	1st day	2nd day	1st day	2nd day
Shorter in the mobile phone	9	7	3	3
Same	10	9	0	0
Longer in the mobile phone	11	14	2	3
N/A	0	0	1	0

Development of GPS-Equipped PDA-Based Activity Diary Survey System

In this chapter, the development of a PDA-based system for collecting data on activity diaries and positioning data is described. Figure 4 shows the PDA tool used in this study. The PDA is "Linux-ZAURUS" by SHARP Corporation, which is equipped with a VGA-size display and runs on a Linux operating system with the Japanese language. The GPS receiver is equipped on the CF (compact flash) slot in the PDA. This system is developed focusing on two points. One is to construct a closed survey environment on the PDA to save telecommunication costs. Telecommunication costs for collecting and storing data are the weak points of mobile-phone-based survey systems, because the cost becomes more expensive as data quantity

becomes larger from one respondent. The other point of focus is to construct a flexible survey system that is easy to expand to other devices such as mobile phones. Considering an application to a certain size of travel-survey, the costs and management of PDA can be a weak point. Therefore, the system was developed as a closed survey system with flexibility for expanding. To ensure these conditions, the questionnaire is developed based on a Web technology. A Web server, a Web browser and questionnaires were installed on each PDA. The PHP (Hypertext Preprocessor) script controls the questionnaire and SQL (Structured Query Language) database language also associates with this system in the data management. The data can be saved in the main memory of PDA at any point of answering questions. Respondents start answering again from the questions not finished yet. The positioning data from the GPS receiver is also stored in the main memory of PDA as a CVS type file by self-made data logger.

FIGURE 4 Snapshot of Linux PDA and GPS Receiver

        The first question of an activity diary is to answer the time of going to bed last night and getting up this morning. Next, respondents are to answer the attributes of the first activity in the day, such as the start time, end time and the type of activity. The alternatives of activities vary according to the current location, in-home or out-of-home. If the current location is in-home, meals, housework, family care, leisure, communications, sleep, parallel activities, and others are listed as the alternatives. If the current location is out-of-home, meals, work/study, daily shopping, non-daily shopping, medical care, family care, leisure, communications/social-activities sightseeing/recreation, sleep, and others are listed as the alternatives. Sleep, meals, and family care are the mandatory activities. Housework, daily shopping, and work/study are categorized as the maintenance activities. Leisure, communication/social-activities, non-daily shopping and sightseeing/recreation are categorized as discretional activities. After finishing of entering the attributes of an activity, the system asks whether the next activity is travel or not, to update the information of the current location. In the question of attributes of travel, several psychological questions are added. For example, in case of travel by car driving, the reason of choosing car driving, the reason and timing of the route choice, the possibility of the route change and the alternatives of the mode are asked to the respondents. After answering the questions associated with the travel, the questions about the reason of location/facility choice and the flexibility/changeability of time allocation are added to

the ordinary questions of the attributes of activities.

The PDA is equipped with a small keyboard and a touch-display system for data input. Respondents use properly these devices according to the type of data at data entry of the survey system. Respondents basically select the answer to the questions from displayed alternatives using a touch pen. Input from keyboard is necessary in case of no adequate alternatives in the list. The system also examines the consistency of the answers and requires corrections if there is any inconsistency in the answers. The collected two types of data, GPS positioning data and activity diary data, are analyzed in a GIS.

The Validity of the PDA-Based Survey

A pilot survey was conducted using the PDA-based system in January 2004, which was a one-week survey on two respondents. After the first survey, the alternatives and construction of the questionnaire were modified based on the suggestions from the respondents. The second empirical survey was conducted in January 2005, which was also a one-week survey on two respondents. In the second pilot survey, we administered a paper-based activity diary survey to the same respondents at the same time to compare the efficiency of the PDA-based survey. The paper-based activity diary survey was a bar-chart type. The reason for adopting a bar-chart type diary was based on the result of our preceding research (*14*).

The result of activity duration for each activity in the second pilot survey is shown in Table 3. The parallel activities are counted doubly and the start time of sleeping is different between consecutive two days. Therefore, the sum of activity durations is different and exceeds occasionally twenty four hours. The figures in parenthesis are the activity duration from the paper-based survey. The bold figures indicate that the activity duration in the paper-based survey is longer than that of the PDA-based survey, and figures with an underline indicate the counter case of the bold figures. The activity durations of mandatory activities were longer in the PDA-based survey, especially in out-of-home activities. As opposed to that, the activity durations of in-home discretional activities and travel were longer in the paper-based survey. These tendencies kept the same during the survey period. Table 4 shows the number of recorded activities. Even the number of activities did not accord between the PDA and paper-based survey.

TABLE 3 Activity Duration of Each Activity Type (One Respondent)

	In-home			Out-of-home			
Day	Mandatory	Maintenance	Discretional	Mandatory	Maintenance	Discretional	Travel
1st	440 (430)	0 (0)	150 (130)	0 (0)	440 (430)	**185 (190)**	**65 (90)**
2nd	**665 (725)**	410 (390)	**300 (310)**	0 (0)	115 (115)	0 (0)	**10 (20)**
3rd	**395 (455)**	280 (280)	*320 (300)*	80 (80)	110 (110)	230 (225)	**85 (110)**
4th	420 (320)	510 (430)	**60 (120)**	**0 (40)**	350 (310)	0 (0)	40 (40)
5th	**420 (740)**	**105 (125)**	**210 (300)**	0 (0)	325 (320)	0 (0)	**80 (85)**
6th	460 (450)	*380 (300)*	**220 (320)**	0 (0)	215 (205)	0 (0)	**25 (35)**
7th	540 (540)	415 (415)	60 (60)	15 (15)	0 (0)	285 (280)	**95 (100)**
8th	630 (625)	610 (550)	**20 (80)**	0 (0)	170 (165)	0 (0)	**70 (80)**

TABLE 4 Number of Recorded Activities

	In-home			Out-of-home			
Day	Mandatory	Maintenance	Discretional	Mandatory	Maintenance	Discretional	Travel
1st	2 (2)	0 (0)	2 (2)	0 (0)	2 (2)	1 (1)	5 (6)
2nd	4 (4)	3 (3)	4 (4)	0 (0)	1 (1)	0 (0)	1 (2)
3rd	2 (2)	2 (2)	1 (1)	1 (1)	1 (1)	2 (2)	6 (6)
4th	2 (2)	5 (4)	1 (2)	0 (1)	2 (3)	0 (0)	4 (4)
5th	3 (4)	3 (3)	4 (4)	0 (0)	2 (2)	0 (0)	4 (4)
6th	4 (4)	7 (7)	3 (5)	0 (0)	2 (2)	0 (0)	2 (3)
7th	2 (2)	3 (3)	1 (1)	1 (1)	0 (0)	4 (4)	5 (5)
8th	5 (5)	6 (7)	1 (2)	0 (0)	3 (2)	0 (0)	6 (6)

CONCLUSIONS

A GPS mobile-phone-based activity diary survey system and a GPS-equipped PDA-based activity diary survey system were developed as intelligent survey methods for collecting activity diary data. Pilot studies were conducted to compare data collected by the mobile devices with data collected by the conventional paper-based questionnaire surveys. From the comparative analyses, the following results were found for the GPS mobile-phone-based survey system:

- Data handling time for the surveyor for data analysis was considerably reduced in the mobile phone survey compared with the conventional paper-based activity diary survey.
- The frequency of data entry was higher in the mobile phone survey than in the conventional survey and the "time lag" between activity implementation and data entry was shorter in the mobile phone. This could be the advantages from flexibility in space and time for recording data.
- Battery consumption in the mobile phone software affected the respondents' activity-travel behavior. The use of telecommunications by mobile phone was also affected for own mobile phone users ("*au*-users").
- Respondents' burden would depend on their characteristics and literacy of mobile phone use in the mobile phone survey.

In the PDA-based survey, the number of activities collected by the paper-based survey was generally larger than that collected by the PDA-based survey. The total activity duration of the paper-based survey, especially of in-home activities and travel, was longer than that collected by the PDA-based survey. It might have been caused by a pre-programmed check system in the PDA software, because the survey system required entering parallel activities strictly and precisely. The respondents might avoid entering data correctly. This is one of the points to be improved through this survey experiment.

There remains space for improvement in the software developed in this study towards a more user-friendly system and more accurate data collection. Future research concerns comparison between the GPS mobile-phone-based system and the GPS-equipped PDA-based system. In the near future, the GPS mobile-phone-based survey or the GPS-equipped PDA-based survey could be used to complement or substitute the conventional paper-based or PC-based activity diary survey methods. Complementation means using a mobile device as a memory jogger for recording out-of-home activities and travels. Substitution means no need of a paper-based questionnaire survey sheet. Geographical presentation of the current position and travel trajectory on the mobile phone or PDA monitor display using a GIS map could contribute to increasing respondents' interest, motivation and willingness to participate in the survey.

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