

GPS MOBILE PHONE-BASED ACTIVITY DIARY SURVEY

Nobuaki OHMORI
Lecturer
Department of Urban Engineering
The University of Tokyo
7-3-1 Hongo, Bunkyo-ku, Tokyo,
113-8656 Japan
Fax: +81-3-5841-8527
E-mail: nobuaki@ut.t.u-tokyo.ac.jp

Morimichi NAKAZATO
Graduate Student
Institute of Environmental Studies
The University of Tokyo
7-3-1 Hongo, Bunkyo-ku, Tokyo,
113-8656 Japan
Fax: +81-3-5841-8527
E-mail: nakazato@ut.t.u-tokyo.ac.jp

Noboru HARATA
Professor
Department of Urban Engineering
The University of Tokyo
7-3-1 Hongo, Bunkyo-ku, Tokyo,
113-8656 Japan
Fax: +81-3-5841-8527
E-mail: nhara@ut.t.u-tokyo.ac.jp

Abstract: Activity diary is necessary information to investigate the relationships between individual travel behavior and activity engagement. A GPS mobile phone-based activity diary survey system is developed in this study. The software programmed in Java works on mobile phone devices for entering information on activity diary. Positional data are automatically collected at regular intervals by GPS-equipped mobile phones. Two pilot surveys are conducted for a total about 50 participants to examine the advantages of the survey system. By comparing activity data collected by the software with the data collected by conventional paper-based activity diary surveys, it is found that the system developed in this study is useful in terms of reducing “time lag” in data entry and mitigation of spatial constraints for data entry. However, the respondent’s burden depends on the characteristics of the respondents.

Key Words: GPS, mobile phone, activity diary survey

1. 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 has been recognized again 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 paper-based activity diary questionnaire sheets for a day or some successive days (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 going back home at night, data accuracy about 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 (Stopher and Jones, 2003).

In recent years, people can make decisions on activity scheduling and travel behavior more dynamically than before, by acquiring information on transport systems and activity opportunities both pre-trip and en-route from various media. Consequently, not only revealed activity-travel patterns but also activity scheduling process has been an interest of transportation researchers. Some researchers have been doing research on the development of computer software for data collection of activity patterns and scheduling process, e.g. CHASE (Doherty and Miller, 2000) and React! (Lee and McNally, 2001). CHASE and React! are computer-assisted self-interviewing (CASI) systems working on PC. Personal digital assistants (PDA) and mobile phone can be also used as a device for data collection (Zhou and Golledge, 2004; Doherty and Papinski, 2004). On the other hand, the use of telecommunications such as mobile phone, e-mail and the Internet, affects individual travel behavior. To analyze interaction between telecommunications and activity-travel scheduling/patterns, information not only on activity diary but also on the use of telecommunications is required. However, methods applied for collecting effectively such kind of data remain uninvestigated research topics. 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 collect detailed information on travel trajectory. The technologies make it possible to automatically collect position (longitude and latitude) and time (and speed for GPS) at a specific interval. To collect positional data using GPS and GSM, respondents are just required to carry the device. There has been a lot of research on travel data collection using GPS and GSM (e.g., Murakami *et al.*, 1999; Draijer *et al.*, 2000; Ohmori *et al.*, 2000; Asakura and Hato, 2004; Arimura, 2004). GPS can be attached to PDA and recently is installed also inside the mobile phone device (see KDDI website). PDA and mobile phone have been also used for data collection as CASI in a wide variety of survey field. Especially, most of the younger people are routinely using mobile phone 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 device 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 GPS mobile phone-based activity diary survey system, and to examine its advantages and disadvantages over conventional surveys, by comparing data collected by the mobile phone survey with those collected by the conventional paper-based survey, and by analyzing participants' preferences in between two survey methods.

2. DEVELOPMENT OF GPS MOBILE PHONE-BASED ACTIVITY DIARY SURVEY SYSTEM

2.1 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 diary 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 life, 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 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 phone, 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 phone 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 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 higher than that of PDA users in Japan – the number of subscribers is about 90 million for mobile phones including PHS, but the number of PDA users would be less than 10 million. From the above reasons, we applied mobile phone 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

There are 4 mobile phone carriers in Japan; NTT DoCoMo, Inc., KDDI Corporation, TU-KA Cellular Inc. and Vodafone K. K. At the time this research was launched into, the only carrier, “au” by KDDI Corporation, that provided mobile phone devices with GPS installed. The “au” employs “gpsOne” which is called the Assisted GPS (see SnapTrack website). It calculates the current position using not only GPS but also information on received signal 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 view of GPS satellites (e.g. inside buildings, at underground stations, etc.) or carried along in coat or jacket pockets. Furthermore, end users can develop original Java application working in 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.

2.2 Development of GPS Mobile Phone-Based Data Collection System

We developed software in the Java language so that respondents can download the software

via web and install it in their own mobile phone. 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 source file arbitrarily. For entering information on activity diary (activity type, start/end time, location, travel mode and accompanied persons) and telephone use (time, media, partner, send/receive and the contents for communications), 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 activity type, location, travel mode and accompanied persons is selected from the predefined list. If 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 “time lag” between activity implementation and activity recorded. 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 reaches 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 is 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 call and e-mail while the software is running. However, they need to end the software to make phone calls and send e-mail, 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 (or enter the name of activity only when select “others”), whereas in the 2nd version, the name of concrete activity type was entered directly from dial buttons. Activity data was transmitted by HTTP in the 2nd version, so respondents’ operation to send data became easier (from pushing two buttons in the 1st version to one button in the 2nd version). 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 in a day. On the other hand, in the 2nd version, transmitted data are automatically added to one data file in the server computer. Outline of the data collection system is shown in Figure 2.

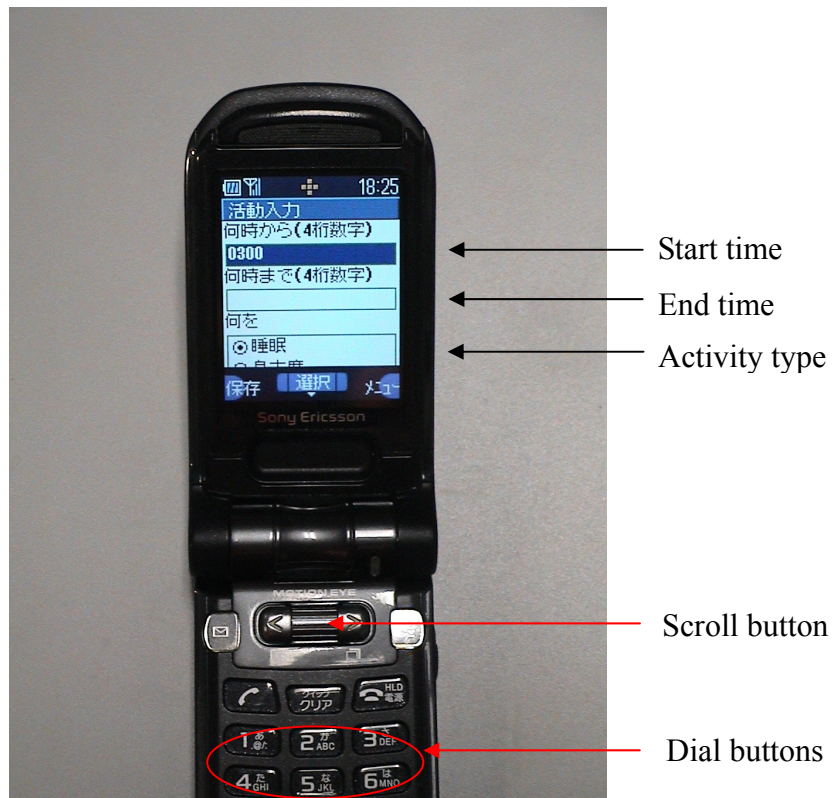


Figure 1. Snapshot of Data Entry Screen in the 1st Version of the System

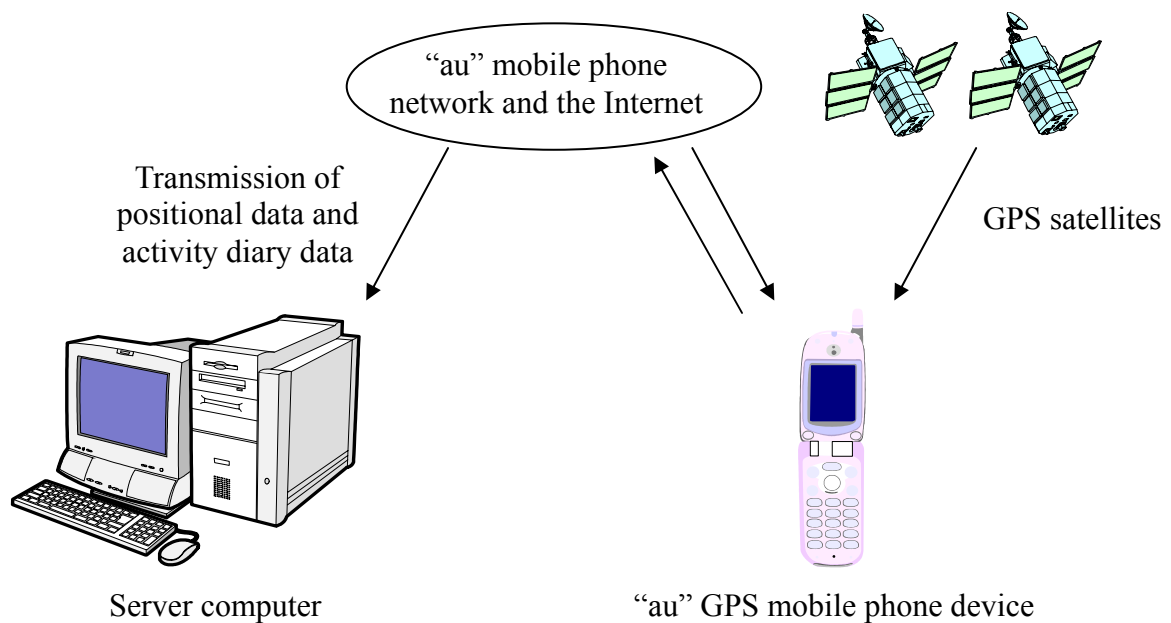


Figure 2. Outline of the Data Collection System

3. ACTIVITY DIARY SURVEY USING THE GPS MOBILE PHONE DEVICE

To examine the advantages and disadvantages of the mobile phone-based activity diary survey

over the conventional paper-based activity diary survey, two pilot surveys were conducted in January and April 2004 for a total about 50 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 38. Thirty three of them were 20's years old and 3 of them were 30's. Thirty one respondents were male. All the respondents were daily using a mobile phone. The average history of mobile phone use was 4.9 years. The respondents were asked to start the software when they wake up and to exit it when they go 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 analysis of "time lag" between activity end time and data entry time. Total 8 of 38 respondents were daily using "au" mobile phone in 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 in 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 ("au non-users"). The "au non-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 in 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. The authors had developed a GIS-based activity-travel simulator, SMAP-E, and applied to a graduate course for the purpose of instructing students to better understand activity-travel behavior under spatio-temporal constraints (Ohmori *et al.*, 2003; Ohmori *et al.*, 2004). One-week activity diary data required for input to SMAP-E had been collected by conventional paper-based surveys. This 2nd survey was also a trial to collect activity diary data by mobile phone for input to SMAP-E. All the 13 respondents were "au non-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 diary in the mobile phone for three days and in the paper-based questionnaire sheet for the remaining four days. Telephone use diary was not recorded in the 2nd survey.

Time interval of GPS tracking was set at 10 minutes. Battery can keep the mobile phone working for 5 to 6 hours under 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. The survey description is summarized in Table 2.

Table 2. Survey Description

	1 st survey	2 nd survey
Number of respondents	38	13
Information collected	1 st day: activity diary 2 nd day: activity diary and telephone use diary	One week: activity diary
Survey media	1 st day and 2 nd day: mobile phone software & paper-based survey sheet	2 nd day-4 th day: mobile phone software 1 st and 5 th -7 th day: paper-based survey sheet
Mobile phone software	1 st version	2 nd version

4. COMPARISON BETWEEN MOBILE PHONE AND PAPER-BASED SURVEY METHODS

4.1 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 an 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 diary 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 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 as:

- two consecutive activities overlapped in timing;
- existence of blank time period; and
- not recorded several in-home activities.

Total 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 in midnight. On the other hand, total 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 in 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 3 shows cumulative distribution of “time lag” from the end time of an activity (activity implementation) and the time when the activity was recorded. As shown in the figure, “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 after 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. Higher frequency and shorter “time lag” suggests that respondents can enter activity information into the mobile phone software at anytime and anywhere, and from clearer memory, so data accuracy could be higher than traditional paper-based survey. 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” was 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” was 200 minutes, 13 minutes and 524 minutes, respectively. Difference of “time lag” between the mobile phone diaries of the 1st and 2nd surveys could be due to difference in survey method and software, but we cannot know the specific reason from this study.

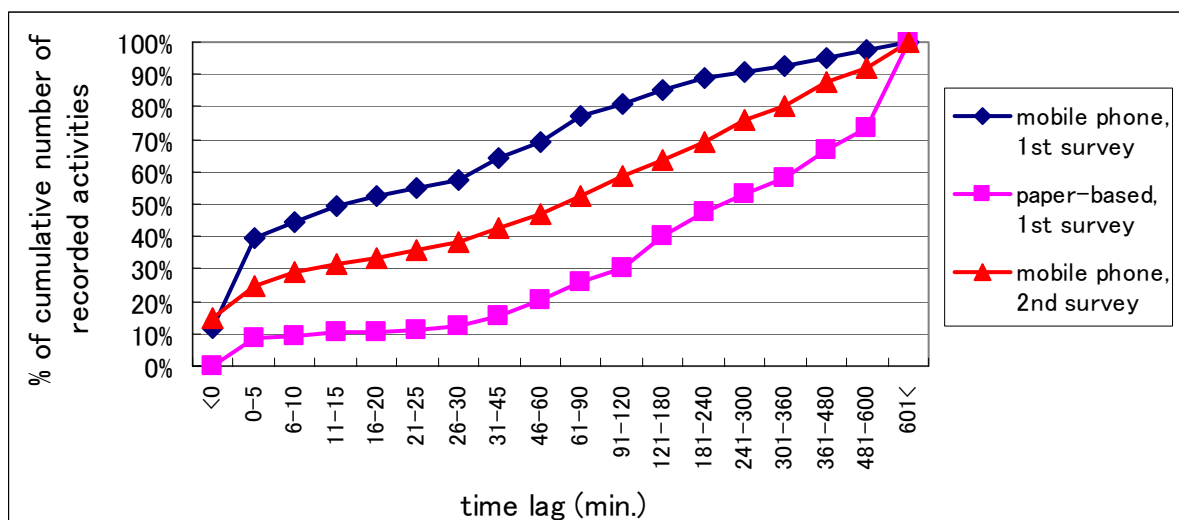


Figure 3. Time Lag between Activity Implementation and Data Entry

Locations where data were recorded

As shown is Figure 4, in terms of locations where activities were recorded, in the paper-based diary of the 1st survey, 67% of the activities was recorded in their home and 32% was in their work or school place. Only 1% of the activities in the paper-based diary was recorded while

traveling. On the other hand, 47% of activities in the mobile phone of the 1st survey was recorded in their home, 22% was in their work or school place and 11% was in other locations. About 20% of the activities was recorded while traveling, of which, 10% was traveling by train, 5% was walking and 1.5% was while riding bicycle. In the mobile phone of the 2nd survey, 35% of the activities was recorded in their home, 35% was in their school place and 20% was in other locations. 35% was recorded while traveling of which 21% was traveling by train, 7.5% was walking and 2% was 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.

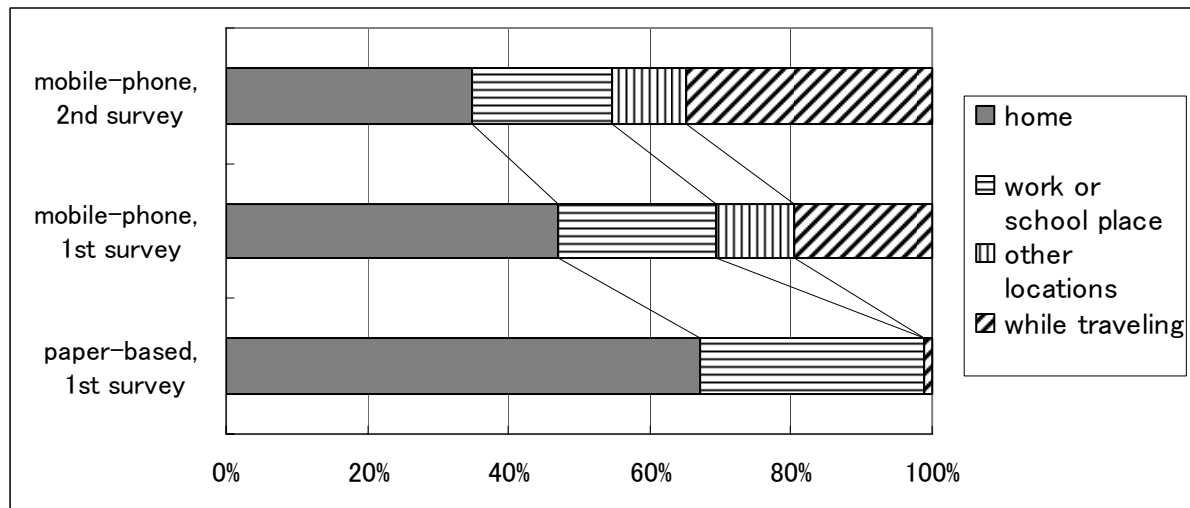


Figure 4. Locations Where Data Were Recorded

4.2 Respondents' Preference in Different Survey Methods

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

Effects of the Mobile Phone Survey on the Respondents' Behavior

Three respondents in the 1st survey answered that they were conscious of being positioned automatically by GPS. Fifteen of them answered that their activity-travel behavior and mobile phone use were at least affected by participating in the survey. 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 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 respondent 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 3 shows the result. For the "au non-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 respondent burden would depend on each respondent's characteristic and her/his mobile phone literacy. For the 2nd day which required to record telephone use diary, more respondents felt time longer in the mobile phone.

Table 3. Respondents' Perceived Time to Complete Data Entry (the Number of the Respondents)

	"au non-users"		"au users"	
	1 st day	2 nd day	1 st day	2 nd 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

5. CONCLUSION

GPS mobile phone-based activity diary survey system was developed as an intelligent survey method for collecting activity diary data. Pilot studies were conducted to compare data collected by the mobile phone software with data collected by the conventional paper-based questionnaire survey. From the comparative analyses, the following results were found:

- Data handling time of the surveyor for data analysis was considerably reduced in the mobile phone survey comparing with the conventional paper-based activity diary survey.
- Frequency of data entry was larger in the mobile phone survey than the conventional survey and "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.
- Respondents' burden would depend on their characteristics and mobile phone literacy in the mobile phone survey.

The authors have been developing an integrated system for data collection, analysis and evaluation of individual/household activity-travel patterns using information and communications technologies, and GIS (Urban Transportation Research Unit, 2004). In this system, activity diary and travel trajectory are the input data for the GIS-based activity-travel simulator. There remain more improvements in the software developed in this study towards more user friendly system and more accurate data collection. In the near future, GPS mobile phone-based survey could be used to complement or substitute the conventional paper-based or PC-based activity diary survey methods. Complement means to use mobile device as a memory jogger for recording out-of-home activities and travels. Substitution means no need of paper-based questionnaire survey sheet. Graphical representation of the current position and travel trajectory on the mobile phone monitor display using GIS map could contribute to increasing respondents' interest, motivation and willingness to participate in the survey.

ACKNOWLEDGEMENTS

The authors gratefully thank to Dr. Yusuke Konishi of Center for Spatial Information Sciences (CSIS) in the University of Tokyo, who developed the original Java program of automatic GPS data collection for "au" mobile phone system, and KDDI Corporation for supporting the surveys.

REFERENCES

- Arimura, M. and Takano, K. (2004) A consideration of the traffic survey by using location information of portable device and recognition of privacy, **Infrastructure Planning Review**, Vol.21, No.4, pp.1019-1026. (in Japanese)
- Asakura, Y. and Hato, E. (2004) Tracking survey for individual travel behaviour using mobile communication instruments, **Transportation Research C12**, pp.273-291.
- Doherty, S.T. and Miller, E.J. (2000) A computerized household activity scheduling survey, **Transportation 27**, pp.75-97.
- Doherty, S.T. and Papinski, D. (2004) Is it possible to automatically trace activity scheduling decisions?, paper presented at **Conference on Progress in Activity-Based Analysis**, Maastricht, the Netherlands, May 2004.
- Draijer, G., Kalfs, N. and Perdok, J. (2000) GPS as a Data Collection Methods in Travel Research, paper presented at the **79th TRB Annual Meeting**.
- Harvey, A. (2003) Time-space diaries: Merging traditions, In P. Stopher and P. Jones (eds.), **Transport Survey Quality and Innovation**, Pergamon, Oxford, pp.151-180.
- KDDI website, <http://www.au.kddi.com/english/index.html>
- Lee, M.S. and McNally, M.G. (2001) Experiments with a computerized self-administered activity survey, **Transportation Research Record 1752**, pp. 91-99.
- Murakami, E. and Wagner, D.P. (1999) Can using global positioning system (GPS) improve trip reporting?, **Transportation Research C7**, pp.149-165.
- Ohmori, N., Muromachi, Y., Harata, N. and Ohta, K. (2000) Travel behavior data collected using GPS and PHS, **Traffic and Transportation Studies: Proceedings of ICTTS 2000**, pp.851-858.
- Ohmori, N., Muromachi, Y., Harata, N. and Ohta, K. (2003) Development and application of GIS-based system for activity-travel patterns under spatio-temporal constraints, **Proceedings of the 8th International Conference on Computers in Urban Planning and Urban Management**, CD-ROM.
- Ohmori, N., Harata, N. and Ohta, K. (2004) Two applications of GIS-based activity-travel simulators, paper presented at **Conference on Progress in Activity-Travel Analysis**, Maastricht, the Netherlands, May 2004.
- SnapTrack Inc. website, <http://www.snaptrack.com/index.jsp>
- Stopher, P. and Jones, P. (2003) **Transport Survey Quality and Innovation**, Pergamon, Oxford.
- Urban Transportation Research Unit (2004) Analysis and evaluation of activity-travel pattern

in an era of IT, exhibited at **11th World Congress on ITS**, Nagoya, Japan, October 2004.

Wermuth, M., Sommer, C. and Kreitz, M. (2003) Impact of new technologies in travel surveys, In P. Stopher and P. Jones (eds.), **Transport Survey Quality and Innovation**, Pergamon, Oxford, pp.151-180.

Zhou, J. and Golledge, R. (2004) Real-time tracking of activity scheduling/schedule execution within unified data collection framework, **TRB 2004 Annual Meeting CD-ROM**.