Two Applications of GIS-Based Activity-Travel Simulators

Nobuaki OHMORI
Department of Urban Engineering
The University of Tokyo
7-3-1 Hongo, Bunkyo-ku, Tokyo
113-8656, Japan
Tel: +81-3-5841-6232
Fax: +81-3-5841-8527
E-mail: nobuaki@ut.t.u-tokyo.ac.jp

Noboru HARATA
Institute of Environmental Studies
The University of Tokyo
7-3-1 Hongo, Bunkyo-ku, Tokyo
113-8656, Japan
Tel: +81-3-5841-6233
Fax: +81-3-5841-6267
E-mail: nhara@ut.t.u-tokyo.ac.jp

and

Katsutoshi OHTA
Department of Regional Development Studies
Toyo University
1-1-1 Izumino, Itakura-machi, Oura-gun, Gunma
374-0113, Japan
Tel: +81-276-82-9026
Fax: +81-276-82-9026
E-mail: kohta@itakura.toyo.ac.jp

To be presented at EIRASS workshop on Progress in Activity-Based Analysis, in Maastricht, The Netherlands, May 28-31, 2004.

Abstract

This paper presents the development and applications of GIS-based activity-travel simulators. Two systems were developed based on the existing system, the Simulation Model for Activity Planning (SMAP) developed by the authors. One application was developed especially for the purpose of instructing students in understanding the theory of space-time prism/accessibility and travel behavior under spatio-temporal constraints. It was used in a graduate course as an educational tool (SMAP for Education: SMAP-E). The other was developed as a decision-making support system for activity planning using interactive surveys to collect information on the activity scheduling process of tourists' leisure activities (SMAP for Leisure: SMAP-L). Both systems were programmed with MapBasic software by customizing MapInfo GIS. In both systems, the time use of a day was represented on a timeline and the spatial component of travel pattern was represented on a map. In addition, the feasibility of alternative activity-travel patterns was tested, based on space-time prism constraints. A GIS database for a transportation network and activity opportunities with some attributes was used in the systems as input. GIS applications of activity-travel simulators were very useful not only for the decision-making support systems but also for the interactive survey tools, which could have wide possibilities contributing to further progress in activity-based analysis.

Keywords: GIS, activity-travel pattern, space-time prism, activity scheduling, simulation

1. Introduction

Understanding mechanism of individual travel behavior in urban space is essential for urban transportation planning and policy. Conventionally, travel is considered a derived demand from the desire to engage in activities at certain locations. Hence, understanding the relationships between travel behavior and daily activity engagement is effective in estimating individual and household responses to policy measures and to changes in environmental constraints. In addition, public policy should provide individuals with a greater set of options to choose from and distribute these options among the population in more equitable ways (Burns, 1979). It is therefore important to evaluate the potential of engaging in activities considering the wide variety of constraints that individuals face. From this view, extensive research has been conducted on the feasibility of engaging in activities under spatio-temporal constraints, referred to as space-time accessibility (see, e.g., Lenntorp, 1978; Burns, 1979; Kwan, 1998, Miller, 1999). Especially in recent years, methodologies to analyze travel behavior in the temporal dimension are necessary for evaluation of the impact of Transportation Demand Management (TDM) policies and Intelligent Transport Systems (ITS) technologies. In addition, travelers can acquire information not only on transport systems but also activity opportunities at pre-trip and en-route from various media such as TV, websites and car-navigation system, so travelers can make decisions about activity-travel pattern more dynamically than before. There has been research on investigating scheduling behavior using data collected by systems such as “CHASE” (Doherty and Miller, 1997) and “React!” (Lee and McNally, 2001) which were developed to trace the process of activity scheduling. Zhou and Golledge (2004) developed a real-time tracking system of activity scheduling/schedule execution on the platform of Personal Digital Assistance (PDA).

Geographic Information System (GIS) is a very effective tool for the management, analysis and representation of spatial elements of the transportation network and individual travel patterns. In recent years, the development of software and the progress of database preparation have contributed to a wide use of GIS in the transportation field (Thill, 2000; Duker and Ton, 2001). GIS has also been used for studies on activity-travel patterns under spatio-temporal constraints (see, e.g., Segawa and Sadahiro, 1995; Kwan, 1998; Miller, 1999). In this context, the ability to visually represent travel patterns in GIS is considered very useful for understanding travel behavior and responses to policy options and to changes of environmental constraints not only for practitioners involved with transportation planning and policy, but also for students studying travel behavior. Moreover, GIS can be used for travel surveys, showing the respondents information on travel patterns, the transportation network and urban environment more realistically. For example, “React!” uses a GIS-based map for collecting activity locations. Spatio-temporal travel tracking data automatically collected with Global Positioning System (GPS) can be also used to represent travel routes and speed profiles. As seen more recently, the three-dimensional visualization of activity-travel patterns using 3D-GIS (Kwan, 2003) can be more powerful to represent individual movement in space-time, which has the possibility to make it easier to understand activity-travel behavior intuitively.

This paper presents the development and applications of GIS-based activity-travel simulators. Two systems were developed based on the existing system, the Simulation Model for Activity Planning (SMAP), developed by the authors. One application was developed especially for the purpose of instructing students in understanding the theory of space-time prism/accessibility and travel behavior under spatio-temporal constraints. It was used in a graduate course as an educational tool (SMAP for Education: SMAP-E) (Ohmori et al. 2003). The other was developed as a decision-making support system for activity planning using interactive surveys to collect information on the activity scheduling process of tourists’ leisure activities (SMAP for Leisure: SMAP-L). Both systems were programmed with MapBasic software by customizing MapInfo GIS. In both systems, the time use of a day was represented on a timeline and the spatial component of travel pattern was represented on a map. In addition, the feasibility of alternative activity-travel patterns was tested, based on space-time prism constraints. A GIS database of the transportation network and activity opportunities with some attributes was used in the systems.

2. GIS-based Activity-Travel Simulators

More than twenty years ago, the Household Activity-Travel Simulator (HATS) developed at Transport Studies Unit (TSU) at Oxford University, essentially a gaming simulation, was used very successfully in trying to better understand household travel decisions and the constraints within which those decisions are made (Jones et al., 1983). On the HATS game board, spatial components of activity-travel patterns were represented on a map and temporal components were represented on a timeline, using information from the activity diaries of all members of a household. When a policy measure was introduced, household members discussed and considered the changes of constraints on the game board and new activity-travel patterns were simulated on this board. The gaming simulation approach was especially interested in inter-personal linkages and constraints, gaining more realistic responses than simply asking hypothetical questions. This tool had originally been developed for policy evaluation but was also used by practitioners and students to understand the interrelationships between activity and travel behavior (Jones, 1982). Other than TSU's study, there have been many works based on gaming simulation or interactive stated response survey methods (for example, Phifer *et al.*, 1980; Burnett and Hanson, 1982; Achmed *et al.*, 1995; Lee-Gosselin and Turrentine, 1997).

It is very important to specify the choice set of feasible activity-travel patterns more realistically. The space-time prism constraint formalized by Hägerstrand (1970) is a very useful concept for specifying alternative feasible activity-travel patterns in space-time. Burns (1979) developed the concept of accessibility to space-time dimensions (space-time accessibility) introducing the activity duration at opportunities based on space-time prism constraints. Lenntorp (1978) operationalized Hägerstrand's approach by developing the PESASP model that calculated the total number of space-time paths given a specific activity program and the urban transport network. CARLA, which was developed at TSU, is a similar model to generate alternative activity patterns of the day, based on combinatorial algorithms (Jones et al., 1983). In recent studies, Kwan (1998) and Miller (1999) operationalized space-time accessibility under the space-time prism on a real world network using GIS. GISICAS (Golledge *et al.*, 1994; Kwan, 1997) is the integration of GIS and computational process model (CPM) for activity scheduling under space-time constraints.

The authors developed the GIS-based gaming simulation system: SMAP, as an innovative integration of GIS and a feasible activity-travel pattern generation model (Ohmori et al., 2003). MapInfo GIS software was used as the system platform. MapBasic programming software was used for customizing MapInfo. Users could operate the system by clicking the added menu bars in MapInfo. In HATS, transparent sheets were used and layered for drawing activity schedule, travel pattern, and transportation network and opportunities (Jones, 1982). Each GIS layer in SMAP substitutes this function. Figure 1 shows the concept of GIS data use in SMAP for the spatio-temporal dimension. The activity-travel pattern generation model could enumerate feasible activity-travel patterns under spatio-temporal constraints of the individual's scheduled activities and opening hours of activity opportunities. With the introduction of two persons' activity schedule constraints, not only private travel modes (walk, bicycle, car-driver and public transport) but also car-passenger mode availability restricted by car-driver's schedule constraints was explicitly dealt with in the model. The series of system operations were logged and saved in a text file, which made it possible for the researcher to post-analyze the simulation results such as respondents' answers to the questions. The initial application of SMAP was aimed to understand constraints that affect travel behavior of the elderly households and their responses to changes of the constraints in a local city in Japan. In particular, showing their one-week activity-travel patterns and places visited on GIS was very useful to examine their lifestyle.

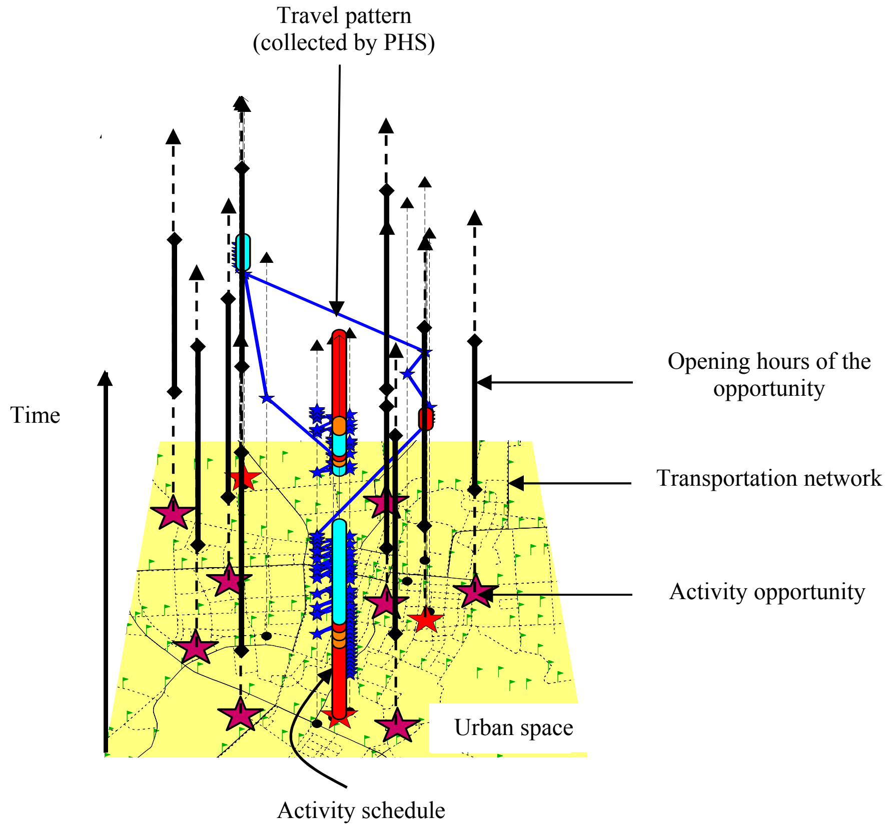
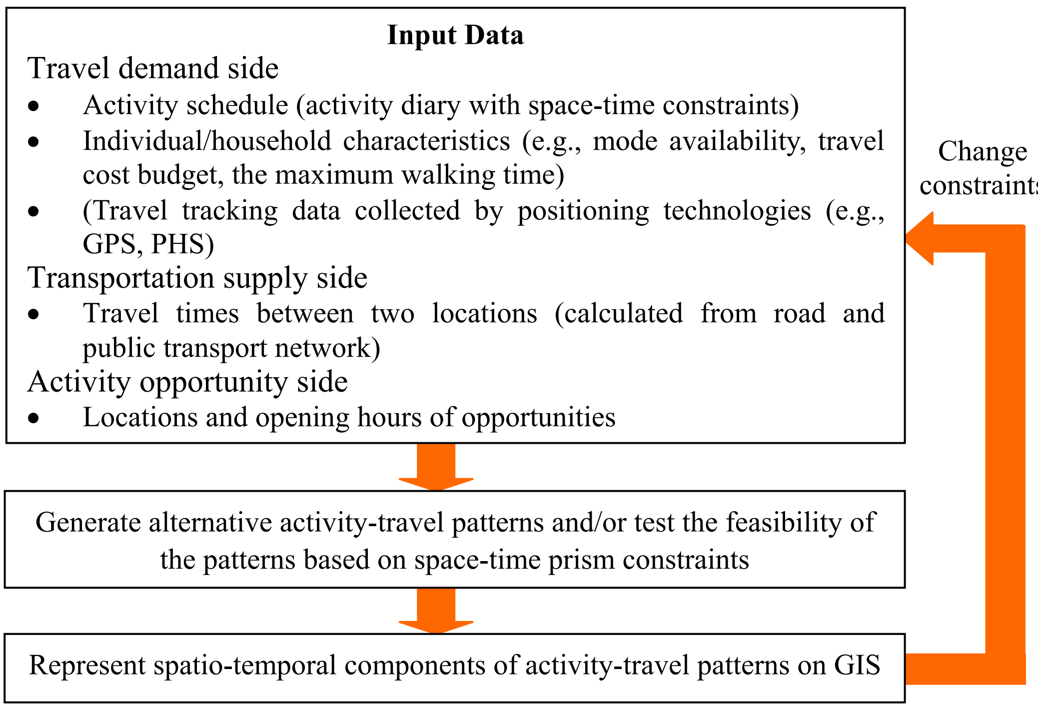


Figure 1. Concept of GIS data use in GIS-based activity-travel simulator (SMAP)



Log file of the operation process is stored in the computer.

Figure 2. Basic structure of GIS-based activity-travel simulator

The authors emphasize that such a GIS-based activity-travel simulator should be useful for mainly two research purposes:

(1) Data collection: as an enhanced interactive GIS-based travel survey tool for collecting data on constraints, response to environmental changes and the scheduling process; and

(2) Traveler's decision-making support: as a simulation tool to analyze alternative activity patterns, providing information on the transport system, activity opportunities, and individual and space-time constraints.

Based on the original SMAP, two applications of GIS-based activity-travel simulator were developed. Figure 2 shows the basic structure of the GIS-based activity travel simulator. Input data consists of travel demand (activity schedule, individual/household characteristics, and travel tracking data), transportation supply (travel times between two locations calculated from transport network data) and activity opportunities (location point and opening hours of activity opportunities). Using the above information, alternative activity-travel patterns are generated and/or the feasibility of the patterns is tested in the system based on the concept of space-time prism constraints. Then, spatial and temporal components of activity-travel patterns are represented in GIS. By changing constraints as input data, changes in alternative activity-travel patterns after environmental change can be simulated. Table 1 shows a comparison of the systems. Characteristics of each system and differences among the systems will be explained in detail after the following sections.

3. Simulator of Space-Time Prism and Accessibility

SMAP-E is a new version of SMAP improved for system users to operate by themselves. The users can simulate potential path area (PPA), which consist of available opportunities with the available time and the feasibility of engaging in an activity in prism constraint. Using real activity schedules from the users' activity diary data enable the users to conduct simulation of more realistic situations in urban environment. The concept of the space-time prism would be easy to understand, if travel speed is assumed to be constant across space for analytical simplicity (the shape of PPA is an ellipse and that of potential path space (PPS) is a combination of two cones). However, in real urban space, the shape of the PPA is not simple, because it depends on the transportation network system. It may be difficult for (under)graduate students to imagine the actual PPA they face in daily life, even if they take a lecture on travel behavior under spatio-temporal constraints to understand the space-time prism theory. For the above reasons, simulation exercises using real activity diary data is considered useful to better understand the concept of prism and space-time accessibility.

3.1 Development of SMAP-E

Since the original version of SMAP required several complicated procedures to operate, an interviewer operated it and respondents answered the questions by looking at a computer screen. In contrast, SMAP-E was developed so that system users could operate it by themselves. Input data consist of three components: travel demand, transportation supply and activity opportunities. Travel demand side data on activity-travel diary with space-time constraints of scheduled activities are necessary for calculation of prisms. Detailed spatio-temporal travel tracking data, collected by positioning technologies such as Personal Handyphone System (PHS) (see Ohmori et al, 2000; Asakura et al., 2001), are used for representing travel routes in GIS. Data on spatio-temporal components of transportation network and activity opportunities are prepared in GIS. Although the only available mode is railway with access/egress by walk in this study, it is enough for the users, who reside in the Tokyo metropolitan area and travel mainly by walk and railway, to simulate their activity-travel patterns. The links in the railway network include attributes of their length and the average travel speed. Travel time through the route of the minimum travel time between two stations is calculated using the railway network. Access and egress mode from an opportunity to railway stations is supposed to be walking. Instead of preparing road network data, access and egress time is calculated from the distance between the opportunity and the railway stations divided by walk speed. Since the timetable of each railway route is not considered in the study, service

Table 1. Comparison between the systems

	SMAP	SMAP-E	SMAP-L
Main study purpose of development and application of the system	To understand activity-travel behavior, and spatio-temporal and inter-personal constraints to out-of-home activities of the elderly household.	To help students understand the theory of space-time prism and activity-travel behavior under spatio-temporal constraints	To understand the scheduling process of tourists' leisure activities
Method	Face-to-face interview	Self completion	Face-to-face interview
Input data (activity schedule)	One-week activity diary of all the household members	One-week activity diary	Pre-planned activity schedule
(transport network)	Road network Bus network	Railway network	Road network
(activity opportunity)	Opportunities which the respondents visited during the reporting week	Opportunities which the respondents visited during the reporting week and railway stations	All the opportunities in a tourism informational magazine
Study area	Local city (Akita city)	Mega city (Tokyo metropolitan area)	Local city (Awaji-shima Island)
Travel mode	Car driver Car passenger Bus with walk access/egress Taxi Bicycle Walk	Railway with walk access/egress	Car
Alternative activity-travel pattern in a prism	One out-of-home discretionary activity by different modes, time of day and day of the week, based on two individuals' prism constraints	One out-of-home discretionary activity by railway and different time of day, based on an individual's prism constraint	Multiple out-of-home activities (trip chain) by car and different routes, based on a party's prism constraint

hours are simply set so that all routes have the same hours. Opportunity data consist of location points and opening hours of all the activity opportunities that the system user visited at during the diary survey week.

SMAP-E is designed for the spatial volume of space-time prism (PPA) and the feasibility of engaging in activities in the prism to be simulated and represented virtually on GIS, before and after the changes of constraints. The C program that is run from a menu bar on the customized MapInfo implements the module calculating PPA and the feasibility of activity in a prism. The PPA and the feasibility of activity engagement are calculated according to the advanced space-time prism concept (see Ohmori et al., 1999; Ohmori et al., 2003). Activities are classified into three types: Activity (a) is fixed activity, Activity (b) is planned but flexible activity and Activity (c) is discretionary activity. Under this assumption, PPA consists of all the opportunities at which the engagement in the target activity is feasible in a prism.

3.2 Application to Graduate Course

SMAP-E has been applied to the course "Environmental Information Exercise in Spatial Planning and Policy" for graduate students at the University of Tokyo in the years 2001, 2002 and 2003. The objective of this exercise was to complement the lecture "Environmental Information System in Spatial Planning and Policy" and to help the students to better understand interrelationships between environmental information and individual activity patterns under space-time constraints. The basic schedule of the exercise is as follows:

- 1st week : Practice spatio-temporal travel tracking data collection using GPS and PHS.
- 2nd week : Record one-week activity-travel diary in a survey sheet, and collect travel tracking data by carrying PHS.
- 3rd week : Learn how to use MapInfo software, and represent PHS data on MapInfo.
- 4th week : Input activity-travel diary data in a Excel sheet, and prepare opportunity data on MapInfo.
- 5th week : Represent and analyze spatial and temporal components of one-week activity-travel pattern.
- 6th week : Submit the first report titled "My one-week activity-travel patterns."
- 7th week : Take a lecture on individual activity-travel patterns under spatio-temporal constraints in urban space.
- 8th week : Take a lecture on transportation network and activity opportunities.
- 9th week : Learn how to use SMAP-E, and simulate activity-travel patterns.
- 10th week : Submit the second report titled "Understanding activity-travel patterns using SMAP-E."

The numbers of students who participated in the exercise were 17 in 2001 year, 11 in 2002 year and 13 in 2003 year. About half of the students had not used any GIS software before the exercise. In the 1st week, the students traveled around Tokyo by car equipped with GPS and PHS for practice of travel tracking data collection. From the 2nd week to the 3rd week, the students recorded their one-week activity diary in a diary survey sheet and carried the PHS device for the purpose of automatically collecting data on spatio-temporal movement. PEAMON (see Asakura et al., 2001) was used in the 2001 and 2003 exercises, and PHS operated by NTT DoCoMo, Inc. (see NTT DoCoMo website) was used in the 2002 exercise. Positional data were collected from morning to midnight at a specific time interval during the reporting week. In the 2001 and 2003 exercises, travel-tracking data were collected using an off-line PHS system, whereas an on-line PHS system was used in the 2002 exercise. Several maps showing their own travel trajectory of that day were sent to the students by e-mail, after 23:00 every other day. They were asked to correct their activity diary recorded in the diary sheet, if any, by checking their travel patterns in the map. PHS systems used in the three exercises are summarized in Table 2.

Table 2. PHS systems used in the exercises

	2001 year	2002 year	2003 year
Number of participants	17	11	13
PHS system	PEAMON	NTT DoCoMo, Inc.	PEAMON
Data collection	Off-line	On-line	Off-line
Time Interval	1 minute	5 minutes	2 minutes
Time period	From 8:00 to 22:00	From 7:00 to 23:00	From 8:00 to 22:00

Before using SMAP-E, the students were assigned to submit their first report on their one-week activity-travel patterns (see the 6th week of the couse schedule). This report was written on the analysis of only travel demand side data, i.e., activity-travel diary and PHS tracking data. Then, the students participated in a lecture on activity-travel patterns under spatio-temporal constraints (activity schedule, transportation network and activity opportunities in urban area). Having basic knowledge about space-time prism and accessibility, the students conducted the simulation exercise using SMAP-E and submitted the second report on activity-travel patterns under spatio-temporal constraints.

3.3 Simulation Exercise Using SMAP-E

One-week activity diary and PHS spatio-temporal tracking data of all users were stored in the server computer. The users were able to access the data via the intranet. The procedure of operating SMAP-E is described below. In the beginning, a user starts a MapBasic program on MapInfo. Then, the user selects her/his identification number and sets constraints such as the maximum walking time. Next, s/he selects a target day from seven days and sets fixed activity scheduling constraints. As shown in Figure 3, time use of the day is represented separately by in-home, travel and out-of-home at the left side timeline. In the timeline, red colored rectangles show fixed activities in space and time (Activity (a)), and blue colored rectangles show discretionary activities (Activity (c)) and travel. Travel trajectory of the day is represented drawn by blue poly-line on the right side map. The C program continuously calculates PPA for all prisms in the day. The PPA can be identified on a map component and simulate the PPA after changing constraints. Actually, railway stations within PPA are displayed and color-coded by the available time at the station (in Figure 3, red indicates 0–30 minutes, yellow 30–60 and green 60–90) as a representative of available opportunities. Furthermore, the user can test the feasibility of engaging in a target activity at a specific site (one of her/his visited opportunities during the reporting week) within a prism (as shown in Figure 4).

As mentioned previously, the objective of the exercise was to help students to understand the important elements directly affecting space-time accessibility. The students were assigned to conduct the following simulation exercises ((1) to (8) correspond to Figure 5):

- Compare the volume of prisms (locations and the number of the railway stations in a prism, classified by the available time) at different time of day, and simulate the volume of a prism before and after changing (1) time budget, (2) distance between fixed activity locations, (3) travel speed and (4) railway service hours.
- Simulate the feasibility of engaging in a discretionary activity in a prism before and after changing (5) the volume of a prism, (6) activity duration, (7) location of an opportunity and (8) opening hours of the opportunity.

Finally, they submitted the second report that consisted of discussion about the simulation results and their opinion about effectiveness and recommended improvement of SMAP-E.

3.4 Analysis of the Students' Reports

From the students' reports, it was found that a series of simulation using SMAP-E had contributed to help students to understand theory of space-time prism and activity-travel patterns under spatio-temporal constraints. In the first report, before the simulation exercises using SMAP-E, there were descriptions about their time use and travel patterns, for example, "Travel time occupied a large amount of a day," "Every day, I sleep for a very long time," "I found that my time use was not efficient," "My activity-travel patterns varied every other day," "I didn't go to any other places than the university, what a boring life!" "It is the first time I identified the travel routes of my trips." These statements indicate that analysis of their own one-week activity-travel patterns by themselves should be effective for looking back on their daily life. In the simulation exercise, on the other hand, the students were able to realize spatio-temporal constraints to their activity-travel patterns by examining not only activity schedule but also transportation network and opportunities. In the second report were a number of descriptions that suggest the usefulness of SMAP-E. Some of the interesting comments on the simulation results are described below:

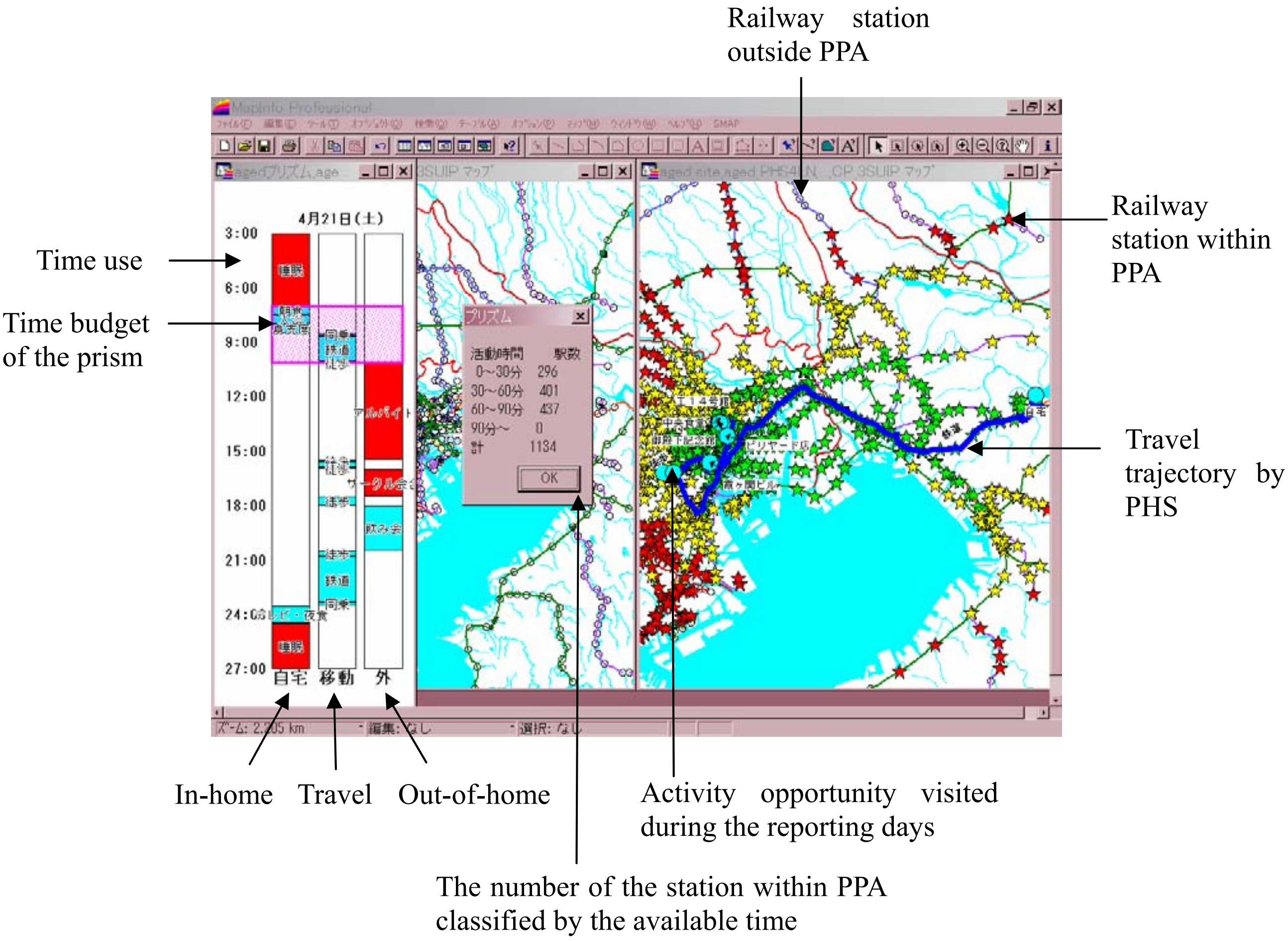


Figure 3. Representation of activity-travel patterns and available opportunities within a space-time prism on SMAP-E

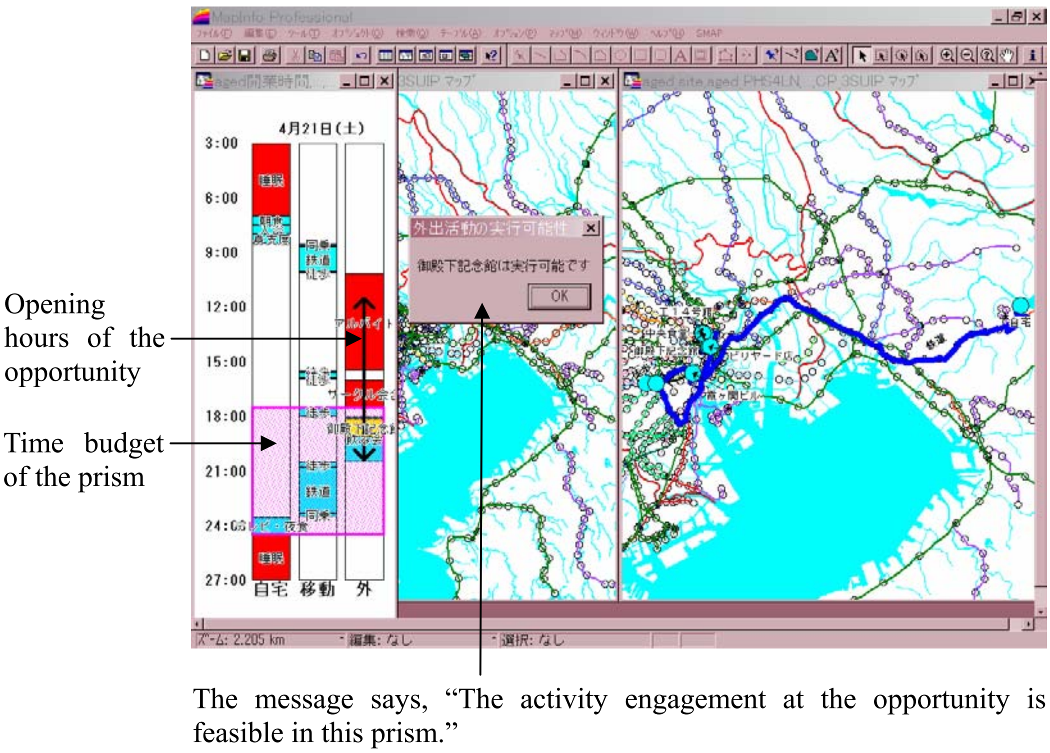


Figure 4. Representation of the feasibility of engaging in the target activity on SMAP-E

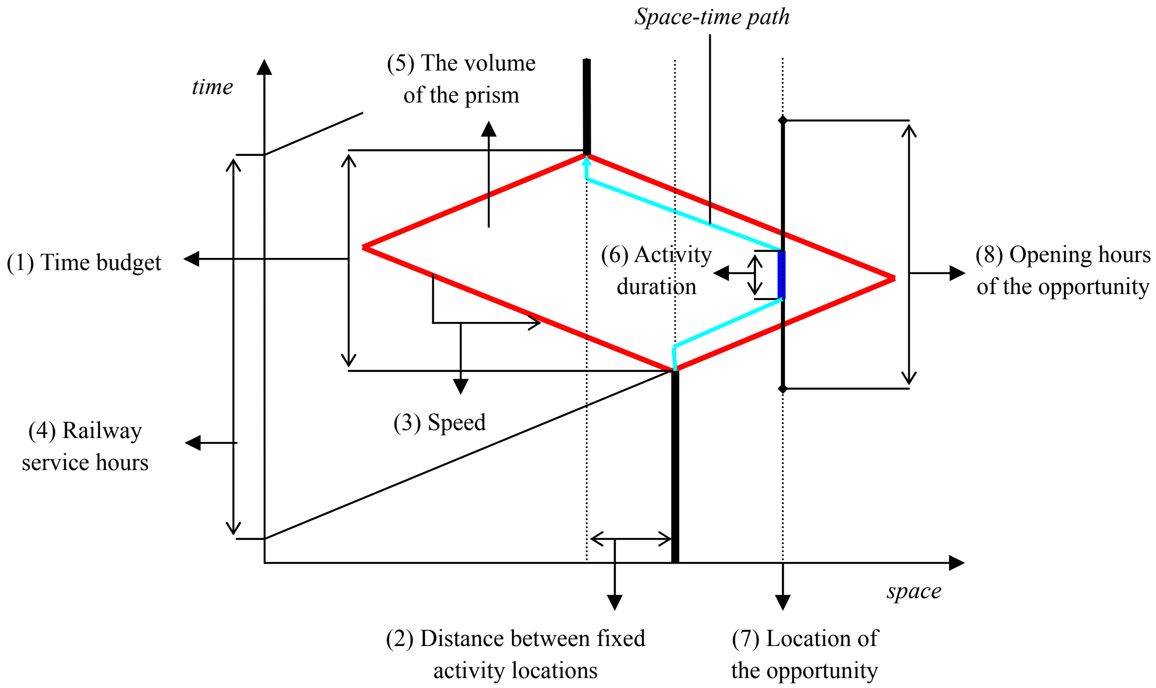


Figure 5. Operational variables in the simulation exercises in SMAP-E

- "Moving to nearer the university contributed both to decreasing travel time and increasing the available time for discretionary activities."
- "Deleting a short-time fixed activity resulted in combining two consecutive prisms and increasing PPA considerably."
- "Getting up earlier enlarged a prism in the morning but did not contribute to increase of the available time at an opportunity. This was because opening hours of the opportunity constrained the available time in the early morning."
- "Comparing the difference of activity type depending on the available time at an opportunity. At a bookstore, 150 minutes are enough for me to browse and choose books, but in 18 minutes, I can search for a book only when I have already decided what book to buy. If only 2 minutes are available at the bookstore, I won't be able to buy any books unless I know where they are placed in the store."
- "I realized that I couldn't actually change the locations or opening hours of any opportunities, or railway speed, but the activity schedule could be coordinated, to some extent, by my discretion."
- "I examined the feasibility of having a lunch activity at two restaurants that located at different places but were reached at in the same travel times, when I wondered why the available times differ in two. Just before submitting this report, I became aware that the opening hours of one restaurant limited the available time in a prism."

SMAP-E was found to be the very effective system for simulating activity-travel patterns after changing major elements affecting space-time accessibility. However, further improvement in the system could enable the users to do more realistic and practical simulation. From the analysis of the students' reports, the following improvements are considered to be useful in the future:

- Introducing travel modes such as walk, bicycle, car driver and bus, in addition to railway: It is important to provide individuals with multi-modal alternatives in transportation policy. Preparing and introducing road and bus network data would contribute to more realistic calculation of travel times by multi-mode.
- Considering the difference of travel times across the day and the week: As for the railway, this is possible by preparing timetable database or integrating public transport information software (for example, "Ekispert" by Val Laboratory Corporation and "Norikae Annai" by Jourdan Co.

Ltd.) with SMAP-E. Although it is difficult to explicitly deal with day-to-day travel time variability on the road network, at least the difference between peak and off-peak periods, and weekdays and weekends should be considered.

- Preparing data on activity opportunities other than those visited during the survey period: It is also important to provide individuals with alternative opportunities in spatial policy. Preparing database about various kinds of activity opportunities will be useful for the users to find new alternative opportunities and activity patterns.
- Indicating the available time length at the opportunity: In the present system, the available time at each station is represented as different colors classified into four or five categories, and the judgment of the feasibility of activity engagement is just "yes" or "no." There were several students who tried to change activity duration step by step and identify the available time length. Giving information on the exact available time at opportunities will be very effective and this function can be easily added to the system.
- Setting up fixed activity schedules more flexibly: Start and end times of prisms are determined by classifying each recorded activity according to fixity in space and time. Thus, increase of time budget can be achieved only by deletion of a fixed activity. Improvement of this point can enable the users to conduct more useful simulation, for example, "What time should I get up to attend the early morning class in time?"

4. Simulator of Leisure Activity Planning

Activity-travel scheduling is a necessary task when people travel and participate in activities. Especially for tourists visiting unfamiliar places, not only travel information (e.g., travel time, route, toll road fee, congestion, accident point, parking places and parking fees) but also activity information (e.g., location, opening hours, entrance fee of opportunities) is useful for traveling and participating in activities efficiently. Usually, tourists can get information on leisure spots (activity opportunities) from a variety of media, such as information magazines, TV and also websites, before leaving home for leisure travel. In recent years, when traveling by public transportation, by inputting information on origin/destination stations and departure/arrival times, travelers can get information on the alternative routes from computer software and websites. Car-navigation systems can also provide information on the shortest route, congestion and accident points on real-time. However, at the present, integrated information on transport systems and activity opportunities is not provided to travelers. Such kind of information should be helpful for leisure activity planning.

4.1 Development of SMAP-L

SMAP-L was also developed on the platform of MapInfo GIS software with MapBasic for its customization. The authors prepared GIS database on road network and activity opportunities in Awaji-shima Island as an input to SMAP-L. The Digital Road Map (DRM), which is the standard road network data in Japan, was used for preparing travel times between two locations in Awaji-shima. Two different travel speeds were set to each link for highway and expressway. The opportunity data were made by the authors and consisted of all the activity opportunities (amusement parks, historic spots, restaurants, etc.) found in the tourism information magazine "RURUBU Awaji-shima'02" with characteristics as activity type, location, opening hours, entrance fee and recommended activity duration to spend at the site. Users of SMAP-L can simulate their activity-travel patterns by successively selecting destinations from the list of opportunities and deciding activity duration at each destination and money spending for travel (toll road and parking fee) and activities (entrance fee and food expenses). SMAP-L automatically searches travel times and routes (of the minimum travel time) between two locations calculated from road network and represents the activity-travel pattern on a map and a timeline on GIS. SMAP-L can check time constraints of the latest time to return home and opening hours of the opportunities, and monetary budget constraint. Also, SMAP-L can give information on alternative opportunities nearer the preceding destination, alternative travel routes with good scenery, recommended activity duration at each opportunity and recommended lunch time. Figure 6 shows a snapshot of SMAP-L. Figure 7 shows a concept of activity scheduling in SMAP-L. As compared to SMAP-E, SMAP-L was used for planning of trip-chain including multiple destinations in a prism. SMAP and SMAP-E produce automatically alternative activity-travel patterns under space-time prism constraints, while in SMAP-L, the feasibility of the activity pattern is tested after making the whole activity schedule.

4.2 Application to One-Day Leisure Activity Planning

SMAP-L was applied to one-day leisure activity planning in Awaji-shima Island to investigate its usefulness for the decision-making support system and to examine travelers' activity scheduling behavior. Awaji-shima Island is located at about 50 km from Osaka city and the travel mode to visit there is almost limited to traveling by car. The main industry on the island is tourism. First, we conducted a questionnaire survey in January 2003 for 33 respondents living in the Osaka metropolitan area, who were recruited by the authors' personal contact. Among the respondents, 3 were university students, 17 were workers and 13 were part-time job workers or housewives. The age of the respondents ranged from the 20s to 60s years old. There were 13 male and 20 female respondents. Only two of the respondents had never visited Awaji-shima Island and 26 had visited there several times before the survey. In the questionnaire survey, respondents were asked about their experience of and attitude toward leisure travel and asked to plan one-day home-based leisure tour schedule to Awaji-shima Island with family members or some friends. Most of the respondents answered that they usually got information on leisure activities from magazines and websites. The information respondents wanted when going-out for leisure activities was what type of activity they can participate in a leisure spot, opening hours of the facility, travel times and routes from their home, weather condition and what kind of food they can have. The information which respondents wanted before starting travel was on leisure spots, whereas during travel was on road congestion.

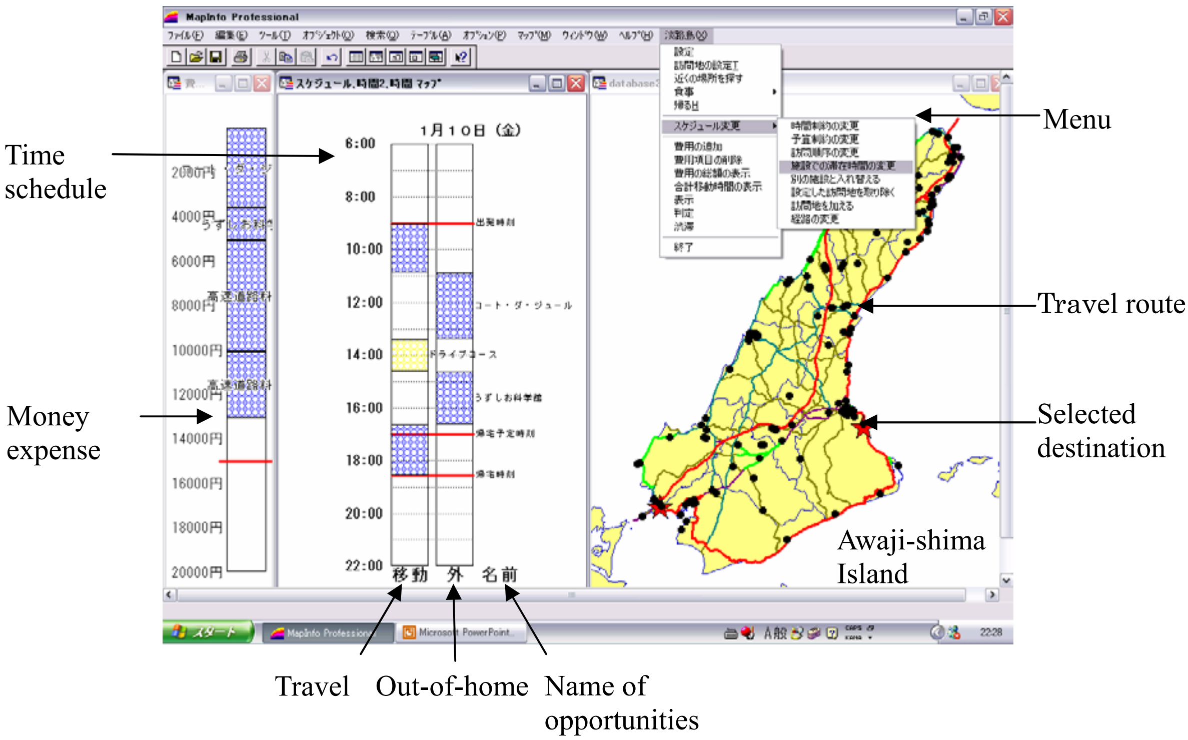


Figure 6. Snapshot of SMAP-L

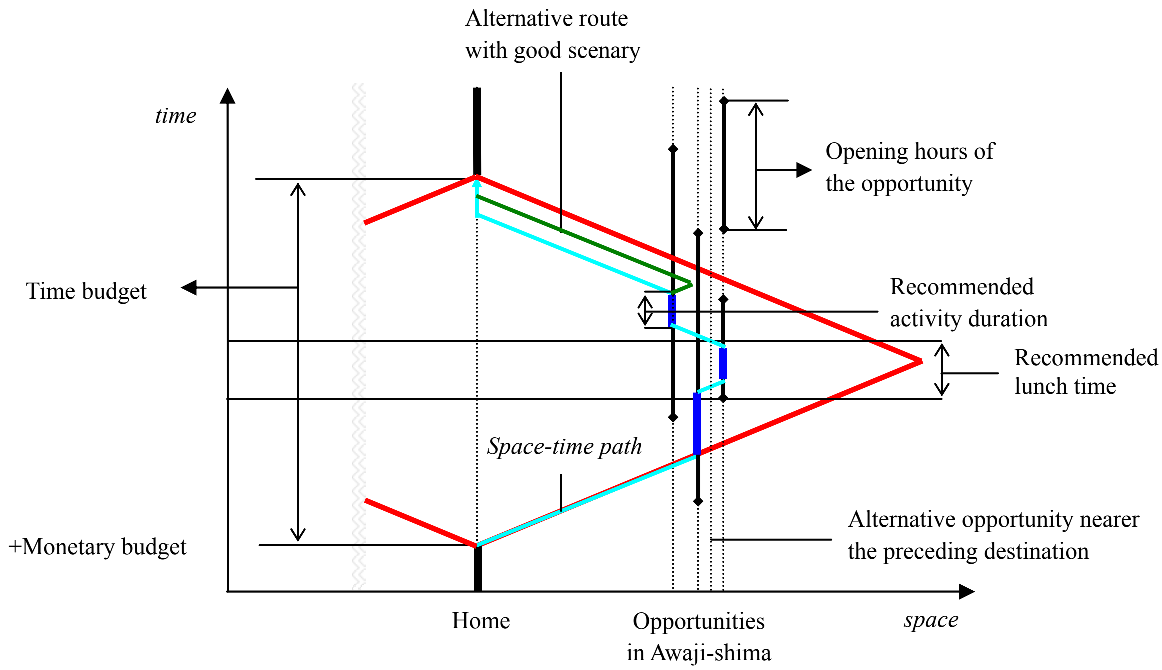


Figure 7. Activity scheduling in SMAP-L

In planning one-day leisure tour schedule to Awaji-shima Island, the respondents were asked to refer only to information in the "RURUBU Awaji-shima'02" magazine to which we had delivered to them in advance. Information in the magazine consists of activity type, brief introduction, explanation of location, telephone number, opening hours and entrance fee of leisure spots and restaurants and a map showing their location and road network. Eighty percent of respondents spent more than 20 minutes to complete the schedule. After that, an interviewer visited their home or office to conduct a face-to-face interview survey. The purposes of the interview were to ask the respondents about their pre-planned activity schedule in detail and to simulate the schedule on SMAP-L. It took about 60 minutes to finish the interview survey per respondent. The interviewer operated SMAP-L on a laptop PC. The respondents looked at a PC screen and answered a series of questions to simulate the pre-planned activity-travel schedule on SMAP-L. First, departure and arrival time at home, monetary budget and the number of travelers were inputted as an initial setting. The respondent selected a destination from a list of leisure spots and activity duration spending at the destination. Then, travel time from her/his home to the first destination and the activity duration were represented on the timeline, and travel route was represented on the map in SMAP-L. The entrance fee at the destination, which was prepared as an attribute of the opportunity database was automatically added to the money expense indicator at the left side. However, the toll road fee and other expenses such as for lunch had to be manually added to the indicator by the interviewer. In the same way, until "going back home," the respondent made decisions about destinations, activity duration and money expenses successively, examining travel time, activity duration, and money expenses for travel and activities. For the respondents who did not have or could not make a complete schedule, for example, in case that "destinations" and the sequence of visiting the destinations were pre-planned but "departure/arrival time" at their home and each destination were not determined, they were asked to make a complete schedule with SMAP-L. A series of operation process of SMAP-L in the interview survey were stored in a laptop PC for post analysis. The interviews were also video-recorded.

4.3 Analysis of Activity Scheduling Process

After the interviews, analysis was carried out on the respondent's scheduling process using data collected with SMAP-L. From the analysis of the pre-planned activity schedule made by the respondents before the face-to-face interview, it was revealed that there was an inter-personal difference of scheduling patterns as shown in Table 3. All the respondents planned "destinations" with visiting sequence in advance, but some of them did not plan or could not decide some elements of activity-travel schedule such as "travel routes," "location of having meals," and "departure/arrival time" at home and each destination. Only 7 of the respondents took into consideration the maximum "monetary budget" spending for travel and activities in the leisure tour. In terms of combination of each element, the scheduling pattern 2, in which destinations, routes, meals and timing were pre-planned, was the most dominant. The number of the respondents classified into the scheduling pattern 4, in which only destinations were pre-planned, was not small (7 respondents were classified into this pattern). Scheduling patterns 1–4 occupied 90% of the total.

Table 3. Scheduling patterns and elements of pre-planned activity schedule

Scheduling pattern	Destination	Route	Meals	Timing	Money	Number of respondents
1	X	X	X	X	X	5
2	X	X	X	X		10
3	X	X	X			8
4	X					7
5	X	X	X		X	2
6	X	X		X		1
Number of respondents	33	26	25	16	7	33

In the face-to-face interview survey, when the respondents were simulating their activity schedule with SMAP-L, sometimes the schedule would not be feasible because of the original time and monetary budget constraints. For example, the following situations occurred: time arriving at home was later than the pre-planned time; and time arriving at the restaurant was before the opening hours. In such cases, they had two alternative responses: "modifying" the current schedule, or "ignoring" the original pre-planned constraints. Figure 8 shows the responses. When arriving at home later than the latest time in which each respondent decided to return home, the most dominant response was "no change," whereas "modification to reduce activity duration at destinations" was seen many times. In contrast, when arriving at a destination "out of the opening hours," the respondents modified the schedule by "changing destinations," or by changing time elements such as "change departure time from home," and "extend" or "reduce activity duration at the preceding opportunity." On the other hand, it appeared that even if the total money expense exceeded the limit of the pre-planned monetary budget, no one worried about money spending for an one-day leisure tour.

At the last part of the interview, the respondents were asked to make comments on advantage and improvement of SMAP-L. The following points are about the inconvenience of SMAP-L as a decision-making support system of leisure travel:

- When confronted with constraints, the respondent had to revise the activity schedule by trial and error. It would be better if the alternative recommended activity schedules are produced automatically.
- There were respondents who did not want to know total money expense. Represented information should be selected by the user.
- The present version is difficult for the respondents to operate. Self-operating software is the

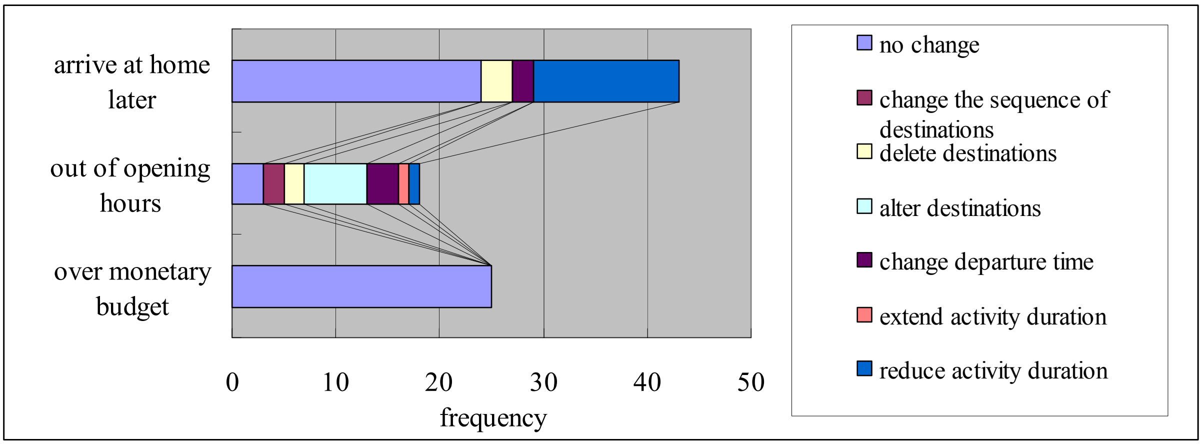


Figure 8. Modification of activity schedule

ultimate development.

- Reliability of information, especially on travel times, is a critical element. Acquiring information on time is desirable and it should be at least updated periodically.
- Some respondents answered that they wanted information on travel distance and fuel consumption. Location and opening hours of gas stations could be very useful information for car drivers.

Nevertheless, if SMAP-L was improved technically in the above points in the near future, more than 80% of the respondents answered that they wanted to use such kind of tool as a decision-making support system when going-out for leisure travel.

5. Conclusions

Two applications of GIS-based activity-travel simulators were developed based on the SMAP which was an innovative integration of GIS and alternative activity-travel pattern generation model. One application was SMAP-E developed especially for the purpose of instructing students in understanding the theory of space-time prism/accessibility and travel behavior under spatio-temporal constraints. It was used in a graduate course as an educational tool. The participants simulated the volume of prism and the feasibility of engaging in a discretionary activity in the prism, using their own one-week activity diary data, before and after changing important variables in activity schedule, transport system and activity opportunities affecting space-time accessibility. From the analysis of students' reports, it was found that a series of simulation using SMAP-E had contributed to help the students to better understand the theory of space-time prism and human activity-travel patterns under spatio-temporal constraints in the urban area, as demonstrated in HATS. SMAP-E was also effective for participants to reflect on their daily life activities. However, there is a still room for improvement of SMAP-E in order to conduct more realistic and practical simulation. This improvement concerns the preparation of the database on network and opportunities, and advanced techniques of programming. The other application was SMAP-L as a decision-making support system for activity planning using interactive surveys to collect information on the activity scheduling process of tourists' leisure tour. Face-to-face interview surveys were conducted with SMAP-L to simulate pre-planned activity schedule of one-day leisure tour. SMAP-L was very useful for supporting decision-making on activity scheduling, providing information on travel times, routes and opportunities, examining time and monetary budget constraints. Data on the scheduling process collected with SMAP-L were used to analyze respondents' scheduling process in activity planning. The analysis revealed the inter-personal difference of scheduling patterns in activity planning and responses when travelers found that the schedule was infeasible under time and monetary constraints. Further research concerns analysis of relationships between activity scheduling and activity pattern using revealed preference data on real leisure tours with SMAP-L.

GIS-based activity-travel simulators developed in this study were very useful as both an interactive survey tool and a decision-making support system. There is a wide possibility of contributing to further progress in activity-based analysis in the near future. First, GIS-based activity-travel simulators can contribute to the evaluation of space-time accessibility measures after introducing various space-time related policy options, such as congestion pricing and flexible working hours. Since the change of travel cost by the introduction of congestion pricing at peak periods affects travel behavior, it would be effective for system users to investigate alternative activity-travel patterns (alternative routes, departure times, destinations and modes) with information on travel cost. In the case of flexible working hours, because the timing of work activity engagement depends on the worker's discretion, not only the volume and timing of prisms but space-time accessibility can be changed. It would be meaningful to investigate the feasibility of engaging in discretionary activities at different working hours when making decision about departure time to commute. Travel tracking data collected by GPS could be also used for representation of detailed travel routes and speed profiles, and for estimation of vehicle emissions. Second, it is very effective to investigate individual travel patterns and advise travelers to encourage environmental friendly travel patterns, as demonstrated in the Travel Blending (Rose and Ampt, 2001) and Travel Feedback Program (Taniguchi et al., 2003). In the future, the GIS-based activity-travel simulator can make it possible for people by themselves to investigate alternative activity-travel patterns and to find more suitable patterns in every situation, which could encourage voluntary behavioral changes. For that purpose, an object function to determine better alternatives should be a key element. For example, it is possible to introduce some object functions to minimize travel times, travel distance, fuel consumption, environmental damage, travel costs, etc., into the GIS-based activity-travel simulator. Also, a system developed on the platform of web-GIS for getting real-time information on travel and activities will be used as an enhanced car-navigation system with a real-time activity-travel scheduling function.

Acknowledgement

The work was funded by The Japan Research Center for Transport Policy and Foundation for Fusion of Science & Technology. Programming of SMAP-L mostly depended on Yoshiaki Shouji. Takuya Maruyama assisted in preparing the railway network data in Tokyo Metropolitan Area. Institute of Urban Transport Planning Co., Ltd. and NTT DoCoMo, Inc. assisted us in using PHS location tracking systems.

References

Achmed, A.K.F., S. Carapetis and M.A.P. Taylor (1995) Rural transport in Bangladesh: Impact of non-motorized transport on households' activity-travel patterns, *Journal of the Eastern Asia Society for Transportation Studies*, 1(3), 893-909.

Asakura, Y., A. Okamoto, A. Suzuki, Y.H. Lee and J. Tanabe (2001) Monitoring individual travel behaviour using PEAMON: a cellular phone based location positioning instrument combined with acceleration sensor, *Proceedings of 8th World Congress on ITS*, CD-ROM.

Burnett, P. and S. Hanson (1982) The analysis of travel as an example of complex human behavior in spatially-constrained situations: Definition and measurement issues, *Transportation Research*, 16A(2), 87-102.

Burns, L.D. (1979) *Transportation, temporal, and spatial components of accessibility*. LexingtonBooks, Lexington.

Doherty, S., and E. Miller (1997) Tracing the household activity scheduling process using one-week computer-based survey, presented at the 8th Meeting of the International Association for Travel Behaviour Research, Austin, Texas, U.S., 1997.

Duker, K. and T. Ton (2001) GIS for transportation, In D.A. Hensher and K.J. Button (eds.), *Handbook of Transport Modeling*. Elsevier, Oxford.

Golledge, R.G., M.-P. Kwan and T. Gärling (1994) Computational process modeling of household travel decisions using a geographical information system, *Papers of the Regional Science*, 73(2), 99-117.

Hägerstrand, T. (1970) What about people in regional science?, *Papers of the Regional Science Association*, 24, 7-21.

Jones, P.M. (1982) *'HATS' educational manual: Studying travel in the context of household activity patterns*. Transport Studies Unit, Oxford University, Ref.193/PR.

Jones, P.M. (2003) Encouraging behavioural change through marketing and management: what can be achieved?, *presented at 10th International Conference on Travel Behavior Research*, Lucerne, Switzerland, 10-15 August, 2003.

Jones, P.M., M.C. Dix, M.I. Clarke and I.G. Heggie (1983) *Understanding travel behavior*. Gower, Aldershot.

Kwan, M.-P. (1997) GISICAS: An activity-based travel decision support system using a GIS-interfaced computational-process model. In: Ettema, D.F. and H.J.P. Timmermans, (eds.), *Activity-Based Approaches to Travel Analysis*, 117-134. Elsevier Science, New York.

Kwan, M.-P. (1998) Space-time and integral measures of individual accessibility: A comparative analysis using a point-based framework, *Geographical Analysis*, Vol.30, No.3, 191-216.

Kwan, M.-P. (2003) Geovisualization of activity-travel patterns using 3D geographical information systems, *presented at 10th International Conference on Travel Behavior Research*, Lucerne, Switzerland, 10-15 August, 2003.

Lee, M.S. and M.G. McNally (2001) Experiments with a computerized self-administered activity survey, *Transportation Research Record*, 1752, 91-99.

Lee-Gosselin, M.E. and T.S. Turrentine (1997) Investigating past and future choice sets of car-users, with special reference to perceptions of safety, *Paper prepared for the 8th Meeting of the International Association of Travel Behaviour Research*, Austin, Texas.

Lenntorp, B. (1978) A time-geographic simulation model of individual activity programmes. In Carlstein, T., D. Parks and N. Thrift (eds.), *Timing Space and Spacing Time 2, Human Activity and Time Geography*. Arnold, London.

Miller, H.J. (1999) Measuring space-time accessibility benefits within transportation networks: Basic theory and computational procedures, *Geographical Analysis*, 31(2), 187-212.

NTT DoCoMo website, http://www.nttdocomo.co.jp/english/index.shtml

Ohmori, N., Y. Muromachi, N. Harata and K. Ohta (1999) A study on accessibility and going-out behavior of aged people considering daily activity pattern, *Journal of the Eastern Asia Society for Transportation Studies*, 3(5), 139-153.

Ohmori, N., Y. Muromachi, N. Harata and K. Ohta (2000) Travel behavior data collected using GPS and PHS, *Traffic and Transportation Studies, Proceedings of ICTTS 2000*, 851-858.

Ohmori, N., N. Harata and K. Ohta (2003) Development and application of GIS-based system for simulating activity-travel patterns under spatio-temporal constraints, *Proceedings of the 8th International Conference on Computers in Urban Planning and Urban Management*, CD-ROM, Sendai, Japan, 2003.

Ohmori, N., Y. Muromachi, N. Harata and K. Ohta (2003) Simulation model for activity planning (SMAP): GIS-based gaming simulation. In Park, C.-H. et al. (eds.), *Selected Proceedings from the 9th World Conference on Transport Research*, CD-ROM, Pergamon.

Phifer, S.P., A.J. Neve and D.T. Hartgen (1980) Family reactions to energy constraints, *Transportation Research Record*, 765, 12-16.

Rose, G. and E. Ampt (2001) Travel Blending: an Australian travel awareness initiative, *Transportation Research*, 6D, 95-110.

Segawa, S. and Y. Sadahiro (1995) A policy making support system for child care facilities using GIS, *Papers and Proceedings of the Geographic Information Systems Association*, 4, 59-64 (in Japanese).
Taniguchi, A., F. Hara, S. Takano, S. Kagaya and S. Fujii (2003), Psychological and behavioral effects of Travel Feedback Program for travel behavioral modification, *82nd TRB Annual Meeting CD-ROM*.
Thill, J.-C. (2000) Geographic information sysems for transportation in perspective, *Transportation Research*, 8C, 3-12.
Zhou, J. and R. Golledge (2004) Real-time tracking of activity scheduling/schedule execution within unified data collection framework, *TRB 2004 Annual Meeting CD-ROM*.