SIMULATION MODEL FOR ACTIVITY PLANNING (SMAP) : GIS-BASED GAMING SIMULATION

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INTRODUCTION

Understanding the decision making process of travelers underlying complex travel behavior is the most significant issue for evaluating the effect of urban transport policy. In 21st century, our society faces big changes such as evolution of information and communication technologies, environmental problems and an aging society. Various policy options for these changes have been taken in urban transport planning. Transportation Demand Management (TDM) measures and Intelligent Transportation Systems (ITS) technologies are very promising for solution to the problems of congestion and environmental damages. Urban infrastructure has been improved under the concept of universal design for the aged society. Decision makers have to consider what groups of individuals and households are affected by a new measure, since each individual and household has specific characteristics and lifestyle, and faces specific environment. Travel is a derived demand from the demand for activity participation and activity-based analysis has been effective to evaluate how travelers respond to the various changes in conditions.

The first comprehensive study of activities and travel behavior is the work at Transport Studies Unit (TSU) at Oxford University more than 20 years ago. Household Activity-Travel Simulator (HATS) methodology, 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, 1980; Jones *et al.*, 1983). On the HATS game board, spatial components of activity-travel patterns are represented on the map, and temporal components are represented on the timelines, using activity diary data of all members of a household. When a policy measure is introduced, household members discuss together considering changes of constraints on the game board, and then new activity-travel patterns are simulated in this board. Gaming simulation approach is especially interested in inter-personal linkages and constraints, gaining more realistic responses than simply asking hypothetical questions. 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).

Generally, decision process of human activity-travel behavior has been considered as two-step decisions—choice set generation and choice from the choice set—and modeling activity-travel behavior has been based on this concept (for example, Bowman and Ben-Akiva, 1996). It is very important to specify the choice set of feasible activity-travel patterns more realistically, when modeling activity-travel behavior and investigating the effects of changes in conditions to activity patterns. The space-time prism constraint formalized by Hägerstrand (1970) is a very useful idea 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 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 one day based on combinatorial algorithms (Jones *et al.*, 1983). These studies generate alternatives of feasible activity-travel patterns. Feasible choice set has been recognized as an important factor especially in destination choice models. Landau *et al.* (1982) calculated shopping destination choice sets based on prism constraints and found that adding temporal constraints to a spatial choice model improved its predictive ability. Thill and Horowitz (1997) demonstrated the effectiveness of the shopping destination choice model with choice set probabilities. In recent studies, Miller (1999) operationalized space-time accessibility under the space-time prism on a real world network using GIS. Although these studies greatly contributed to analyses of feasible activity-travel patterns in space-time, they are individually based analyses and do not explicitly incorporate interactions among household members. Recker (1995) developed the model of pick-up and delivery problem under household inter-personal and temporal constraints, but initial applications have been limited by solution algorithm.

On the other hand, Geographic Information System (GIS) is a very promising tool for handling and analyzing spatial data. There is a possibility that GIS helps spatial visualization and data management in gaming simulation techniques. GISICAS (Golledge *et al.*, 1994; Kwan, 1997, 1998) is the integration of GIS and computational process model (CPM) for activity scheduling under space-time constraints. The concept of this model is extended to travel decision support system for the dynamic decision under the use of Advanced Traveler Information Systems (ATIS). However GISICAS does not incorporate multiple travel modes, and use GIS mainly for managing input data on network and locations. Data on activity opportunities are not dealt with as real locations but the center of zone, and then opening hours are not realistic.

The objectives of this study are mainly to enhance gaming simulation methods using GIS capability and to understand the elderly household activity-travel patterns by interactive surveys. A GIS-based gaming simulation tool is developed linked to the model generating alternative activity-travel patterns, which is named Simulation Model for Activity Planning (SMAP). SMAP improves previous gaming simulation practices by introducing space-time visualization on GIS, and feasible activity patterns are calculated based on space-time and inter-personal constraints. Generation of feasible alternative activity patterns is based on the idea of advanced space-time prism classifying activities into three types according to fixity of timing, duration and location of activities. Moreover, pick-up behavior within family members and trade-offs of multi-day activities are examined using household members' one-week activity diary data. Applications of SMAP to elderly households are presented, aiming at understanding the elderly people's travel behavior and responses to changes in conditions.

DEVELOPMENT OF SIMULATION MODEL FOR ACTIVITY PLANNING (SMAP)

GIS-BASED GAMING SIMULATION

The outline of SMAP is described below. Interactive surveys on GIS can be conducted using SMAP to understand household constraints and to examine responses to changes in conditions. Figure 1 shows the outline of SMAP model structure.

Generally, based on the previous study, the space-time prism is determined by fixed activities and transportation network, in addition to these two factors feasible activity-travel patterns participating in out-of-home activities in the prism are determined with activity opportunities. *Input data* for SMAP consist of data on travel demand side (individual and household characteristics and activity schedule), transportation supply side (network travel time between nodes by mode and time of day calculated using 4

transport network data) and opportunity side (location point and opening hours of each activity opportunity). Data concerning travel demand side include home location points, mode availability, travel time/cost budget, and activity schedule of household members. Activity schedule contains activity type, start and end time, location and priority. Priority of each activity is introduced as space-time constraints of time of day, duration and location of each activity (the details are described in the next subsection).

Data about transport supply side are network travel times between nodes by mode and time of day, which is calculated using road network data and public transport network data (only bus in this study). Digital Road Map (DRM), which is the standard road network data in Japan, is used as road network data in the study. Since digital data on bus network do not exist especially for local cities, we made bus network data on bus stops, routes and frequency by ourselves. Travel times between all nodes are calculated by a C program using minimum path algorithms. Travel time by car (car driver, car passenger and taxi), bicycle and walk is calculated using road network. Travel time by bus is calculated as minimum generalized travel time on routes, using equivalent coefficients (Nitta *et al.*, 1995) considering travel resistance by each mode as not only boarding but also access/egress walking, transfer and waiting (Ohmori *et al.*, 1999).

Data for opportunity side consist of location and opening hours of activity opportunities. Digitalized data on address of opportunities are available in major cities, but data on opening hours of opportunities are not available and need to be made manually on GIS referring to "paper map" and telephone directory. Opening hours are used as temporal constraints for specifying feasible activity-travel patterns in a prism

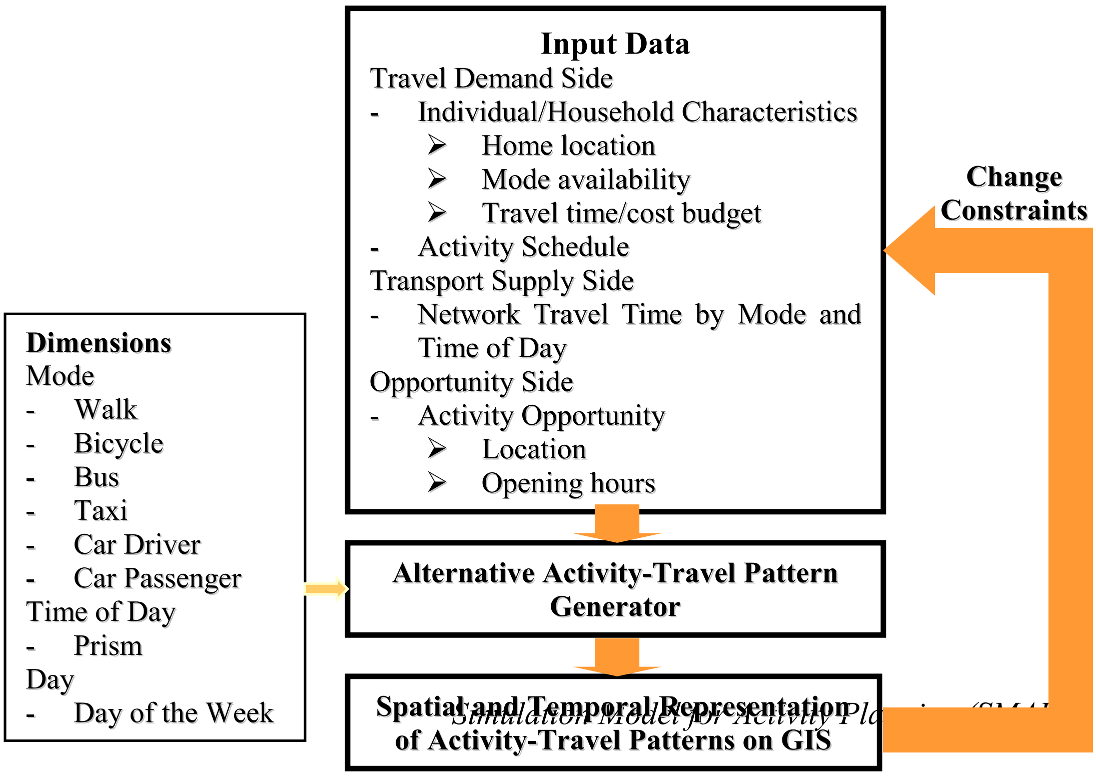


Figure 1. Outline of Simulation Model for Activity Planning (SMAP)

determined by activity schedules. Spatial data on opportunities and network are managed in the form of longitude and latitude. All spatial data are also used as background data for representation of activity patterns on GIS.

Alternative activity-travel pattern generator, which is the program written in C, is a model generating, via enumeration of sampling choice sets, feasible patterns like PESASP and CARLA. Alternative activity-travel patterns for one target out-of-home activity, depending on mode and time of day, are calculated within space-time prism constraints. Firstly, nearest network node from each opportunity location (including home) is searched based on information of longitude/latitude. Then feasibility of participation in out-of-home activities in a prism by each travel mode is calculated, using activity schedule, point-to-point travel time between opportunities and opening hours, as described in the next subsection. The calculated results are used as input to next component of SMAP that is space-time representation of activity-travel patterns.

Spatial and temporal representation of activity-travel patterns on GIS: Spatial and temporal components of reported activity-travel patterns and alternative activity-travel patterns generated by *the alternative activity-travel pattern generator* are represented on GIS (in the study MapInfo software is used). The way of representation in space-time is based on the HATS game board. By changing environmental constraints as input data, for example, mode availability, travel time budget, travel cost budget, activity schedule, travel speed and opening hours, alternative activity-travel patterns after change of constraints are also calculated and represented. Respondents examined the changes and alternatives, and are asked to select a new activity pattern among alternatives represented on GIS.

Alternative Activity-Travel Pattern Generator

In calculating choice sets of feasible alternative activity-travel patterns, SMAP is based on the following assumptions of individual activity scheduling decisions (Ohmori *et al.*, 1998; Ohmori *et al.*, 1999). An individual has main planned activities (in this study, this type of activity is defined as activity (a)) in the day, and firstly these activities are scheduled, which are assumed that time of day, duration and location engaged in these activities are fixed. These activities could also be considered as most prioritized activities. Secondly, planned but flexible activities (activity (b)) are scheduled, of which duration and location are fixed but time of day is flexible within specific time period. Finally, non-planned and discretionary activities (activity (c)) are engaged in the open periods. As you know, travel may be derived from demand for participation of all of these activities.

In a traditional concept of space-time prism developed by Hägerstrand, time periods are divided into two types: open periods and blocked periods. An individual has the option of traveling and engaging in activities in open periods. On the other hand, the individual is committed to engage in fixed activities at fixed locations in blocked

periods. Therefore activities are classified into two types: activity (a) and (c) using the terms defined in this study. In daily life, people have such kind of activities as activity (b) which is planned to do and only total duration and location are fixed but time of day is not fixed, for example, house cleaning, food preparation and personal care. In SMAP, introduction of the idea of activity (b) enables to model travel behavior that is adjusting timing of engaged in out-of-home discretionary activities both to opening hours of opportunities and to other members' activity scheduling constraints, considering limited time budget for activity (c) and travel. If an individual X has an activity schedule consisting of n activities (a), the number of space-time prisms formed in the day is $(n - 1)$. In this study, it is assumed that the end time of n_X-th activity (a) is the earliest start time of n_X-th prism and the start time of $(n_X + 1)$-th activity (a) is the latest end time of n_X-th prism. Components of the individual X's activity-travel pattern are defined as:

$TS_{n_X}^X$, $TE_{n_X}^X$: The earliest start time and the latest end time of the n_X-th prism of individual X

L_i^X, L_j^X: Locations where the n_X-th prism of individual X starts and ends

L_k: Location of opportunity k

$\sum AT_{b,n_X}^X$: The sum of the duration of activities (b) in which individual X engages between times $TS_{n_X}^X$ and $TE_{n_X}^X$

$t_{m,ij}$: Travel time from location i to location j by mode m

T_k: Activity times that individual X participates in the target activity at opportunity k

OS_l^k, OE_l^k: The l-th start time and end time in a day of opportunity k

$Trip\_Start\_Time_{n_X}^X$: Travel start time of individual X in the n_X-th prism

($TE_{n_X}^X - TS_{n_X}^X - \sum AT_{b,n_X}^X$) is the amount of time for participating in activities (c) and travel for individual X. Individual X can participate in the target out-of-home activity at opportunity k in the n_X-th prism within the amount of available time ($TE_{n_X}^X - TS_{n_X}^X - \sum AT_{b,n_X}^X$), only when s/he starts traveling after $TS_{n_X}^X$ by mode m, arrives at location L_k after OS_l^k, participates in the activity for T_k, leaves before OE_l^k by mode m and arrives before $TE_{n_X}^X$. If positive number of $Trip\_Start\_Time_{n_X}^X$ exists subject to equations (1) through (5), individual X has the option to do the out-of-home activity at opportunity k in the n_X-th prism.

$$Trip\_Start\_Time_{n_X}^X \geq TS_{n_X}^X \tag{1}$$

$$Trip\_Start\_Time_{n_X}^{X} + t_{m,L_i^X L_k} \geq OS_l^k \qquad (2)$$

$$Trip\_Start\_Time_{n_X}^{X} + t_{m,L_i^X L_k} + T_k \leq OE_l^k \qquad (3)$$

$$Trip\_Start\_Time_{n_X}^{X} + t_{m,L_i^X L_k} + T_k + t_{m,L_k L_j^X} \leq TE_{n_X}^{X} \qquad (4)$$

$$TE_{n_X}^{X} - TS_{n_X}^{X} - \sum AT_{b,n_X}^{X} \geq t_{m,L_i^X L_k} + T_k + t_{m,L_k L_j^X} \qquad (5)$$

Under this assumption, alternative activity-travel patterns for one target out-of-home activity are calculated within space-time constraints, allowing for variation in mode, time of day and day of the week. Although it is assumed that an individual has minimum time necessary for each kind of activity participation, in the study the observed time in activity diary data is used as activity time T_k . In addition, pick-up mode availability is also introduced explicitly considering space-time constraints of two persons' activity schedules in SMAP. Classified into four patterns are whether the pick-up mode (car passenger) is available for individual *X* by individual *Y* as a driver, figures 2.1 to 2.4 show examples of two individuals' prisms, space-time paths and opening hours of the opportunity when pick-up mode is available. Likewise individual *X*, components of individual *Y*'s activity schedule are defined as:

$TS_{n_Y}^{Y}$, $TE_{n_Y}^{Y}$: The earliest start time and the latest end time of the n_Y-th prism of individual *Y*

L_i^Y , L_j^Y : Locations where the n_Y-th prism of individual *Y* starts and ends

$\sum AT_{b,n_Y}^{Y}$: The sum of the duration of activities (b) in which individual *Y* engages between time $TS_{n_Y}^{Y}$ and $TE_{n_Y}^{Y}$

$t_{car,ij}$: Travel time from location *i* to location *j* by car

$Trip\_Start\_Time_{n_Y}^{Y}$: Travel start time of individual *Y* in the n_Y-th prism

1. Pick-up mode is available in the reported trip

Pick-up mode is available when a prism of individual *Y* contains the individual *X*'s trip in space-time (figure 2.1). In this case, out-of-home activities of individual *X* are assumed to be activity (a) and a prism is formed as shown in figure 2.1. Constrained by the activity schedule, individual *Y* can leave location L_i^Y after $TS_{n_Y}^{Y}$ and go to L_i^X to pick up individual *X* to location L_k , and has to be in location L_j^Y before $TE_{n_Y}^{Y}$. If positive numbers of both $Trip\_Start\_Time_{n_X}^{X}$ and $Trip\_Start\_Time_{n_Y}^{Y}$ exist subject to equations (1) and (6) through (10), individual *X* has the option to travel using pick-up mode by individual *Y* in the trip.

$$Trip\_Start\_Time_{n_Y}^{Y} \geq TS_{n_Y}^{Y} \qquad (6)$$

$$Trip\_Start\_Time_{n_X}^{X} + t_{car,L_i^X L_j^X} \leq TE_{n_X}^{X} \qquad (7)$$

$$Trip\_Start\_Time_{n_Y}^{Y} + t_{car,L_i^Y L_i^X} + t_{car,L_i^X L_j^X} + t_{car,L_j^X L_j^Y} \leq TE_{n_Y}^{Y} \qquad (8)$$

$$TE_{n_X}^{X} - TS_{n_X}^{X} - \sum AT_{b,n_X}^{X} \geq t_{car,L_i^X L_j^X} \qquad (9)$$

$$TE^Y_{n_Y} - TS^Y_{n_Y} - \sum AT^Y_{b,n_Y} \geq t_{car,L_i^Y L_i^X} + t_{car,L_i^X L_j^X} + t_{car,L_j^X L_j^Y} \tag{10}$$

Next, feasibility that pick-up mode is available for participation in the target out-of-home activity at another timing (prism) is examined. In this case, the following three patterns are tested according to differences of travel directions "to" and "from" the opportunity.

2. Pick-up mode is available in the trip "to" the opportunity k in individual X's prism

When the individual X's n_X-th prism and the individual Y's n_Y-th prism overlap in space-time as shown in figure 2.2, in other words, if positive numbers of both $Trip\_Start\_Time^X_{n_X}$ and $Trip\_Start\_Time^Y_{n_Y}$ exist subject to equations (1), (6) and (11) through (16), pick-up mode by individual Y is available for individual X in the trip only "to" the opportunity k, and individual X can participate in the target activity and travel from location L_k to L_j^X by mode m other than pick-up mode.

$$Trip\_Start\_Time^X_{n_X} + t_{car,L_i^X L_k} \geq OS_l^k \tag{11}$$

$$Trip\_Start\_Time^X_{n_X} + t_{car,L_i^X L_k} + T_k \leq OE_l^k \tag{12}$$

$$Trip\_Start\_Time^X_{n_X} + t_{car,L_i^X L_k} + T_k + t_{m,L_k L_j^X} \leq TE^X_{n_X} \tag{13}$$

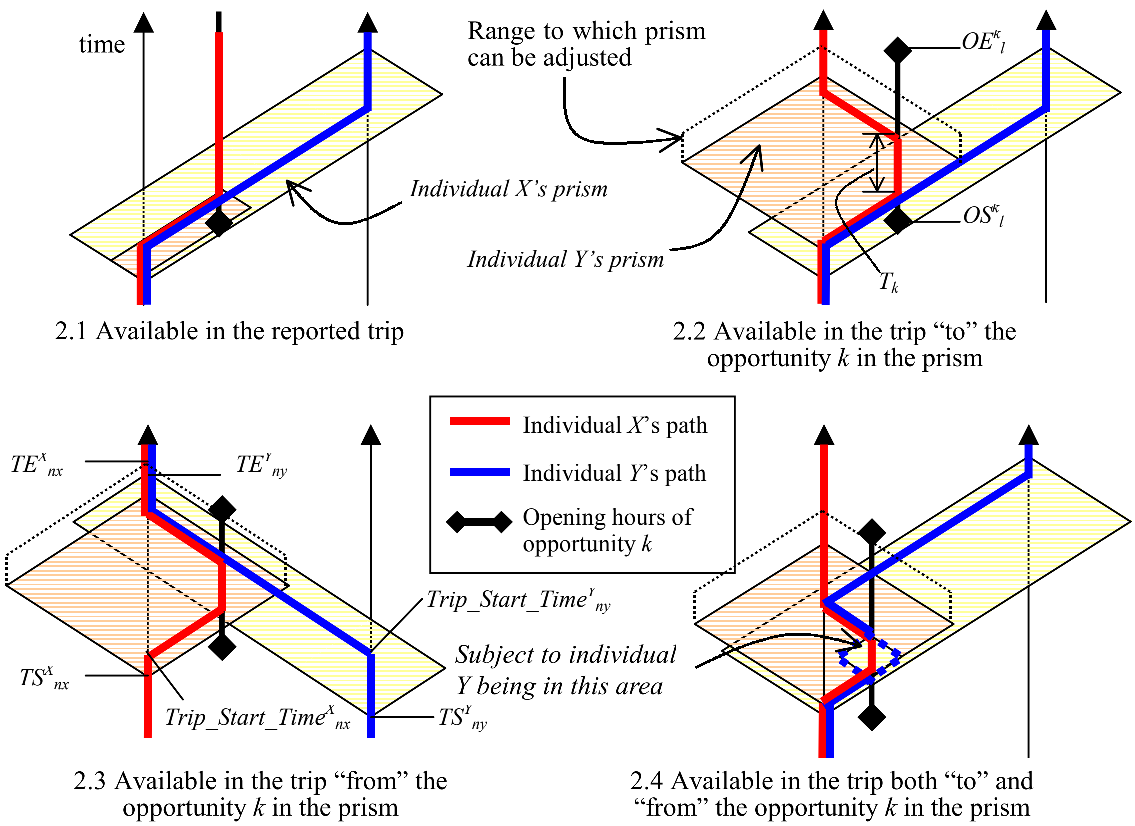
$$Trip\_Start\_Time^Y_{n_Y} + t_{car,L_i^Y L_i^X} + t_{car,L_i^X L_k} + t_{m,L_k L_j^Y} \leq TE^Y_{n_Y} \tag{14}$$

$$TE^X_{n_X} - TS^X_{n_X} - \sum AT^X_{b,n_X} \geq t_{car,L_i^X L_k} + T_k + t_{m,L_k L_j^X} \tag{15}$$

$$TE^Y_{n_Y} - TS^Y_{n_Y} - \sum AT^Y_{b,n_Y} \geq t_{car,L_i^Y L_i^X} + t_{car,L_i^X L_k} + t_{m,L_k L_j^Y} \tag{16}$$

3. Pick-up mode is available in the trip "from" the opportunity k in individual X's prism

When prisms of individual X and individual Y overlap in space-time as shown in figure 2.3 and positive numbers of both $Trip\_Start\_Time^X_{n_X}$ and $Trip\_Start\_Time^Y_{n_Y}$



exist subject to equations (1), (6) and (17) through (22), pick-up mode is available for individual X in the trip only "from" the opportunity k.

$$Trip\_Start\_Time^X_{n_X} + t_{m,L^X_i L_k} \geq OS^k_l \tag{17}$$

$$Trip\_Start\_Time^X_{n_X} + t_{m,L^X_i L_k} + T_k \leq OE^k_l \tag{18}$$

$$Trip\_Start\_Time^X_{n_X} + t_{m,L^X_i L_k} + T_k + t_{car,L_k L^X_j} \leq TE^X_{n_X} \tag{19}$$

$$Trip\_Start\_Time^Y_{n_Y} + t_{car,L^Y_i L_k} + t_{car,L_k L^X_j} + t_{car,L^X_j L^Y_j} \leq TE^Y_{n_Y} \tag{20}$$

$$TE^X_{n_X} - TS^X_{n_X} - \sum AT^X_{b,n_X} \geq t_{m,L^X_i L_k} + T_k + t_{car,L_k L^X_j} \tag{21}$$

$$TE^Y_{n_Y} - TS^Y_{n_Y} - \sum AT^Y_{b,n_Y} \geq t_{car,L^Y_i L_k} + t_{car,L_k L^X_j} + t_{car,L^X_j L^Y_j} \tag{22}$$

4. Pick-up mode is available in the trip both "to" and "from" the opportunity k in individual X's prism

When prisms of individual X and individual Y overlap in space-time as shown in figure 2.4 and positive numbers of both $Trip\_Start\_Time^X_{n_X}$ and $Trip\_Start\_Time^Y_{n_Y}$ exist subject to equations (1), (6) and (23) through (28), pick-up mode is available in the trip both "to" and "from" the opportunity k. In this case, individual Y has to be within the specific space-time area during individual X participates in the activity at opportunity k.

$$Trip\_Start\_Time^X_{n_X} + t_{car,L^X_i L_k} \geq OS^k_l \tag{23}$$

$$Trip\_Start\_Time^X_{n_X} + t_{car,L^X_i L_k} + T_k \leq OE^k_l \tag{24}$$

$$Trip\_Start\_Time^X_{n_X} + t_{car,L^X_i L_k} + T_k + t_{car,L_k L^X_j} \leq TE^X_{n_X} \tag{25}$$

$$Trip\_Start\_Time^Y_{n_Y} + t_{car,L^Y_i L^X_i} + t_{car,L^X_i L_k} + T_k + t_{car,L_k L^X_j} + t_{car,L^X_j L^Y_j} \leq TE^Y_{n_Y} \tag{26}$$

$$TE^X_{n_X} - TS^X_{n_X} - \sum AT^X_{b,n_X} \geq t_{car,L^X_i L_k} + T_k + t_{car,L_k L^X_j} \tag{27}$$

$$TE^Y_{n_Y} - TS^Y_{n_Y} - \sum AT^Y_{b,n_Y} \geq t_{car,L^Y_i L^X_i} + t_{car,L^X_i L_k} + T_k + t_{car,L_k L^X_j} + t_{car,L^X_j L^Y_j} \tag{28}$$

The algorithm described above only deals with space-time constraints, after this the feasible alternatives are reduced by individual capability constraints as mode availability, maximum walking time per trip and maximum travel cost per day. Feasibility of participating in the target activity on a different day is also tested using this algorithm. Since location and duration of the target activities is fixed in the model, alternative patterns only of mode, time of day and day of the week are generated. This could be extended to introducing choice set of locations and durations. In the model, it is supposed that the individual must do activities (b) within the same prism, but the algorithm could be extended to within another prism of the day or another day.

Enhanced Gaming Simulation Techniques in GIS

The alternative activity-travel pattern generator described above is linked to GIS, thus constructing a GIS-based gaming simulation tool. Not only observed activity-travel patterns but also alternative patterns calculated by *the alternative activity-travel pattern generator* can be represented on GIS. The part of user interface of SMAP program for a series of operations is written in MapBasic software, which is special addition to MapInfo. The features of SMAP are summarized as the followings:

1. Advantages from the use of GIS

Visualization of activity-travel patterns on digital maps and time grids (temporal components are drawn in another window), showing only appropriate information case by case

- Capability of zoom in/out of the specific spatial area and time period
- Easiness of changing input data on not only individual and household characteristics but also level of service of transport network and opportunities on GIS

2. Advantages from linking to alternative activity-travel pattern generation model

- Realization of feasible alternatives explicitly considering space-time and physical capability constraints
- Examination of pick-up mode availability introducing inter-personal linkages among household members explicitly considering two persons' prism constraints
- Dealing with alternatives for one out-of-home activity, depending not only mode and time of day but also day of the week using multi-day activity diary data

Since several indicators about activity-travel patterns are also calculated and presented, for example, the number of trips, travel time by mode, travel cost and activity duration by activity types, respondents can examine the alternatives referring to not only spatial and temporal representation but also this quantitative information.

APPLICATIONS TO THE ELDERLY HOUSEHOLDS

SMAP was applied to elderly households to understand constraints of daily activity patterns and responses to changes in conditions. Generally the elderly have a variety of physical capability constraints, for example, some of them can not drive a car, can not walk so long distance, feel resistance to using public transport and keep regular hours in daily life in order to keep their health. Also coupling constraints are significant because they want cooperation of other people, for example, they sometimes want to be picked up by other family members. Therefore activity-based analysis considering various constraints should be effective to understand elderly people's travel behavior. The survey procedure consists of two main phases: (1) the completion of a self-administered activity diary and (2) household interactive in-depth interview, based upon the SMAP gaming simulation procedure.

SURVEY DESCRIPTION AND DATA COLLECTION

In November 1999, a total of 12 elderly household interviews were carried out in Akita city. Akita is the city where the prefectural government of Akita prefecture locates. Akita prefecture is expected to be the most aged one in Japan in about 20
years from now. Population of the city is about 300,000 and the ratio of the elderly is about 14%. Public transportation used by inhabitants is mainly bus. The recent trend is that car dependency increases and large opportunities move from the city center to suburbs, while the level of bus service decreases.

In advance of main interview surveys, one-week activity diary data were collected of family members over 15 years old in 13 elderly households (20 retired elderly and 10 non-elderly people). In this survey, not only out-of-home activities but also in-home activities were asked to record in the questionnaire sheets. Spatio-temporal behavioral data during the survey period were collected automatically using PHS (Personal Handyphone System) location tracking system at the same time (Ohmori *et al.*, 1999). PHS is originally a cellular phone system in Japan. When a person has PHS, data on location (longitude and latitude) and time can be collected automatically at the specific time intervals. Each positional data has about 100 meters error. In this study, PHS data were used for help to specify only locations where respondents had visited during the survey period, although travel routes could be estimated using spatio-temporal tracking data collected by PHS (Asakura *et al.*, 2000).

Data on locations and opening hours of all activity opportunities (about 100 sites) including the respondents' homes and working places that 30 respondents visited during survey period are prepared on GIS. Home is assumed to be available all the day and information about opening hours of other opportunities such as shopping sites were arranged by telephone interviews to each facility. Travel times by mode and time of day between opportunities are calculated using detailed transportation network data as described in the previous section.

The household in-depth interviews were conducted according to the SMAP gaming simulation procedure. The SMAP program is installed in a notebook PC and an interviewer visited respondents' home with it. For single elderly household, interview is conducted for one respondent. Since the present version of SMAP can deal with two persons' activity patterns at the same time, for household more than two persons, "main-respondent (elderly people)" and "sub-respondent (who can drive a car)" are selected in the household.

First part of the interview procedure is intended for understanding the reasons for the observed behavior. Respondents are asked about their mode availability, maximum walking time per trip and maximum travel cost per day for initial settings. After selecting a target day from one-week (the activity diary survey period), spatial and temporal components of the respondent's activity pattern of the day is represented on 12 *The 9th WCTR Selected Proceedings*

GIS. Travel pattern is represented as arrows between two locations in a digital map. Time spent on "in-home" and "out-of-home" activities and "travel" is represented on

different sections in vertical timelines of 24 hours starting at 3:00 a.m. All activities of the day are classified into three types as described in the previous section according to the respondent's answers. All elderly respondents are retired and non-working people in the survey, and then location of fixed activities (activities (a) in the study) in their schedule is only their home: activities (a) are sleep and eating according to the answers for the elderly, activities (a) of other members are sleep, work and study. Then *the alternative activity-travel pattern generator* generates alternatives about each out-of-home activity depending on mode and prism. The interviewer asks the reasons and various constraints of choosing the current activity-travel patterns of the day comparing with alternatives.

After this, they are asked how they would modify the activity pattern under changes of constraints. In this survey, the following changes in conditions were introduced:

- Community bus, which is a very comfortable bus for the elderly in Japan, is available only once a week. Bus stop is located in front of the respondent's home.
- Giving up driving due to physical constraints of aging for car drivers.
- Using an electronic car that is very easy to operate (the car is under development in Department of Engineering Synthesis, the University of Tokyo).

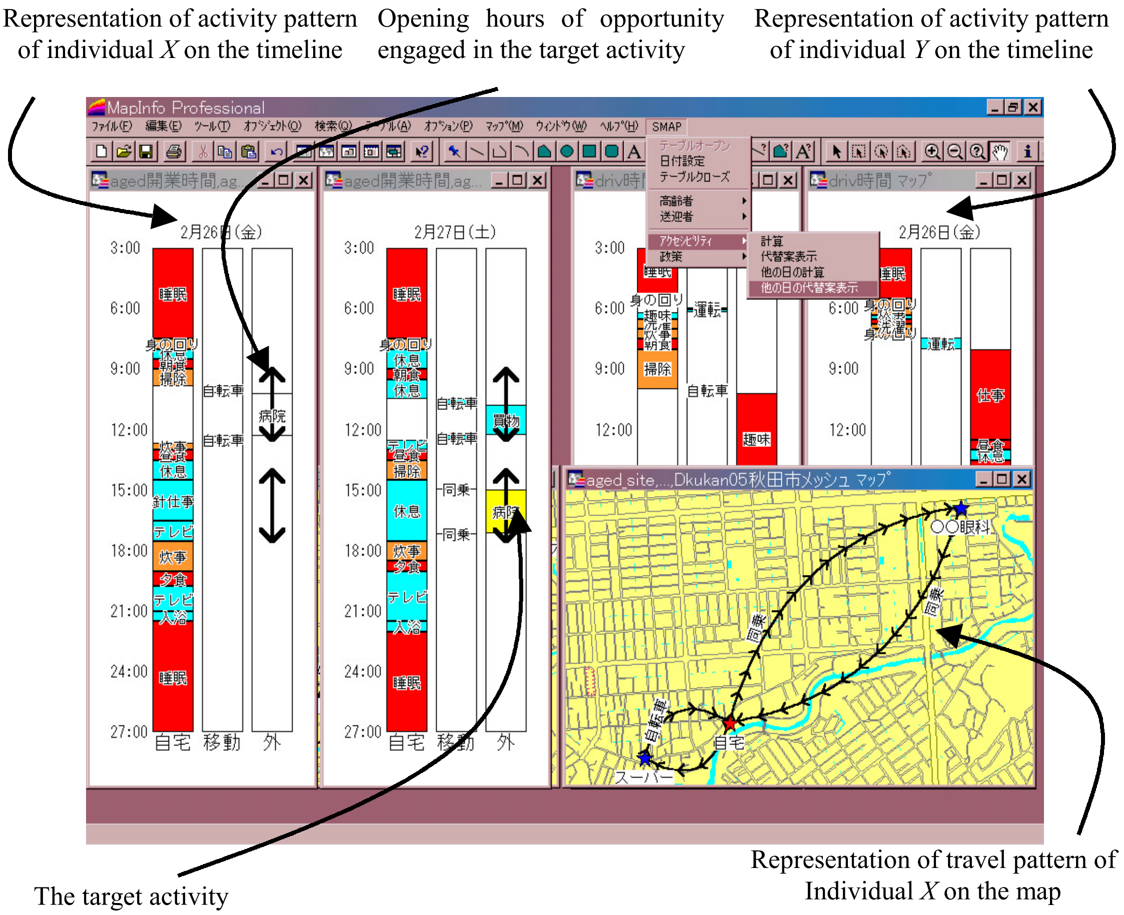


Figure 3. Screenshot of SMAP (change the target activity of going to hospital, from by bicycle in the morning on Friday to by car-passenger in the afternoon on Saturday)

- Extended opening hours of the opportunity for the target activity or this is also available on holiday.

By changing input data on travel demand, transport supply and opportunity, the choice set of alternative patterns after changes is calculated by *the alternative activity-travel pattern generator*. New feasible patterns for participating in the target activity are represented on GIS, and the respondent is asked to select one activity pattern, that is day of the week, time of day and mode. For the respondent living with other members who can drive in the household, "car passenger" mode is included in the choice set. Two persons' activities are represented simultaneously as shown in figure 3. If "main-respondent" selects an alternative traveling by car passenger mode, the interviewer asks "sub-respondent" whether s/he would accept her/his pattern including added serve passenger activities. Opening hours are represented as both directional arrows in the temporal part: in the figure 3, two arrows mean the opening hours of the opportunities consist of two parts (morning and afternoon). Data on initial settings, changes of constraints, alternatives, selected patterns and survey procedures are stored in PC for post analyses. A series of interviews were also video-recorded, so that the discussions can be analyzed in depth subsequently.

UNDERSTANDING OF CONSTRAINTS AND RESPONSES TO CHANGES IN CONDITIONS

Through the interview surveys, many detailed and individual specific constraints were understood and various responses to changes in conditions were identified. In this paper, only two examples are described and discussed below. Figures 4 and 5 shows the activity-travel patterns and prism constraints by mode in space-time, the observed ones at left side and the stated ones after changes of conditions at right side. In the figures, three prisms are formed in the activity pattern of the elderly: after breakfast and before lunch, after lunch and before dinner, after dinner and before sleep. Differences of prism size means differences of travel speed by mode.

The first example is the case in which opportunities are available on weekends (figure 4). She is 89 years old and lives with her son, her son's wife and her grandson. Her available travel modes are walk, taxi and car passenger. On weekdays, her son works outside (at opportunity C in the figure 4) and pick-up mode is not available for her. A hospital (opportunity A) is open only on weekdays, so she goes to the doctor by taxi on a weekday. If the hospital is available on weekends, she answered she would go to see the doctor by pick-up mode by her son's driving and he also accepted her answer. Another hospital (opportunity B) is also open in the afternoon, but her good friend comes to the hospital in the morning, so every time she goes to the hospital in the morning to meet the friend. She habitually doesn't go out after having dinner because of darkness outside, therefore she has no options of doing out-of-home activities in the prism formed between dinner and sleep.

The second example, in another household, is that in case community bus is available

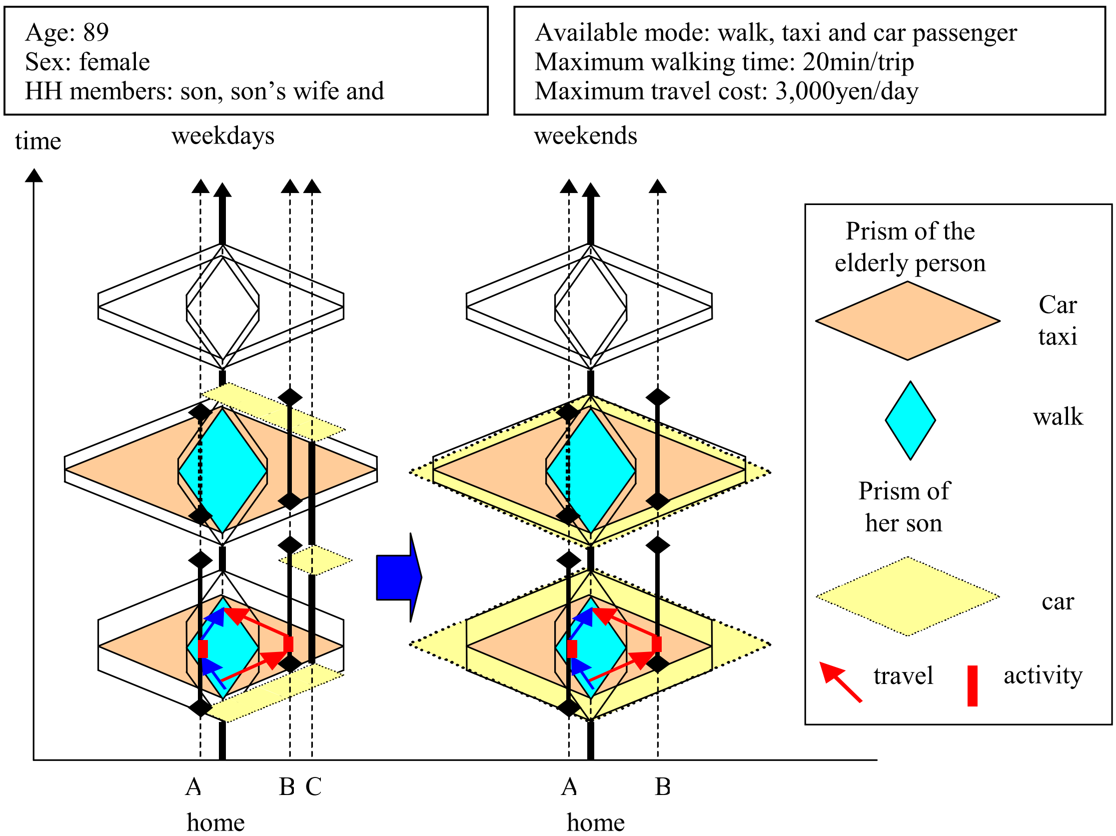


Figure 4. In case of opportunities available on weekends

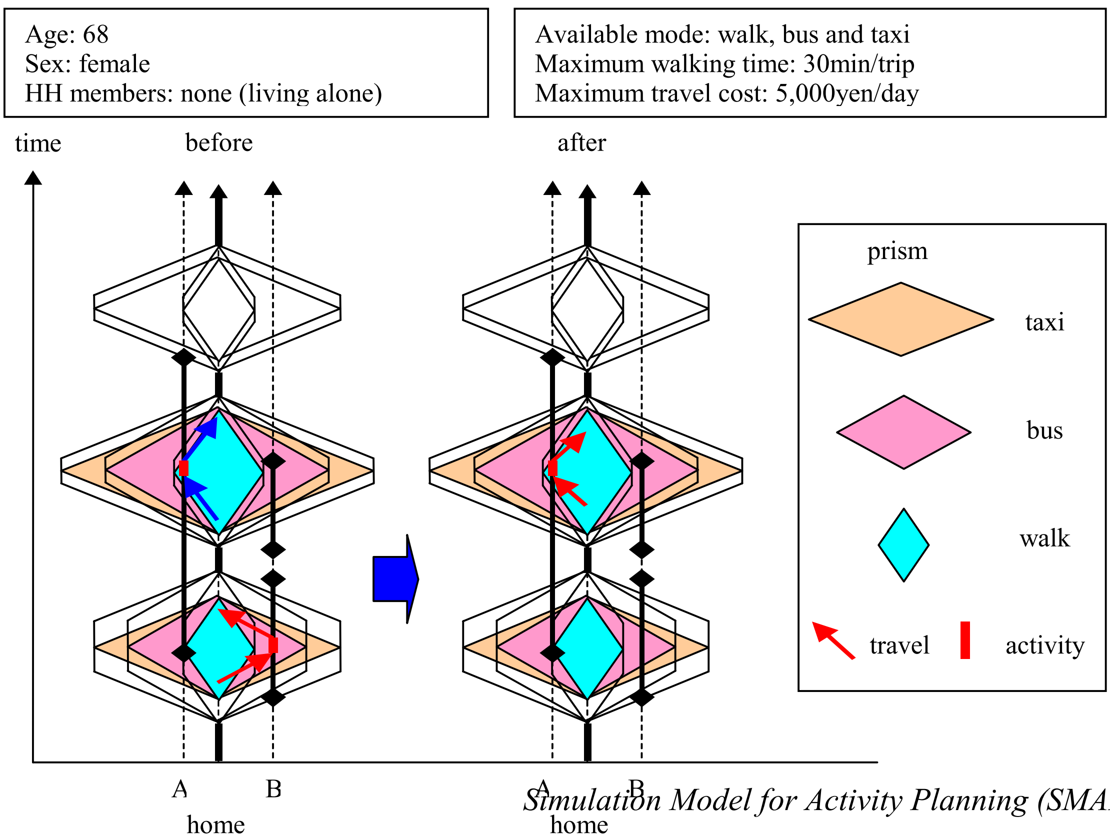


Figure 5. In case of community bus available once a week

once a week (figure 5). She is 68 years old and lives alone. She cannot drive a car, and her available travel modes are walk, bus and taxi. She walks to a supermarket (opportunity A in figure 5) and goes to a hospital (opportunity B) by normal bus.

When community bus is in service once a week, for example on Wednesday, she answered she would go to the supermarket using community bus on Wednesday, but she would not go to the hospital by community bus on Wednesday because her doctor receives patients only on Monday and Thursday. Bus is not in service after p.m. 8:00 o'clock, so a prism of bus does not exist at night. She habitually doesn't go out after having dinner, either.

Other important constraints to activity-travel patterns of the elderly were found in the 13 household interview surveys. These are the followings:

1. Constraints concerning travel mode
- Intend to walk as much as possible for health, but it is difficult to walk to and from a opportunity, due to physical constraints, so walk in only one way and use other mode in the other way
- Use bicycle for small purchases, car for larger purchases
- Does not go to downtown by bicycle because of fear of danger for vehicles running in downtown
- Does not drive a car during congested time periods because of difficulty to park

2. Constraints concerning time of day
- Habitually go out before noon and spend time relaxing in the home on afternoon
- (Inversely) do housework and rarely go out before noon
- Go out in the morning because of availability of pick-up mode by other family member living with
- Go to a supermarket just on time when the supermarket opens, in order to buy discount goods
- Go to hospital in the morning when not so many patients come

Last part of interview was questions about SMAP interview procedure. Although it took long time, about 1 to 1.5 hours, to complete the interview, respondents paid much attention to the PC screen and they were very interested in this high-tech method. Some of the respondents answered that they were able to look back to daily activity and travel behavior, and others were surprised at their very small action space. A few respondents answered that temporal component of activity pattern was a little difficult to understand. These answers suggest that SMAP could help to evaluate a person's activity pattern and support his decision making of activity planning, but improvement of temporal representation would be needed for application to the elderly.

CONCLUSION

In this paper, Simulation Model for Activity Planning (SMAP): GIS-based gaming simulation tool linked to alternative activity-travel pattern generator, was developed based on HATS. SMAP is unique and useful at the points: (1) the advanced space-time prism is introduced by classifying activities into three types according to fixity of timing, duration and location of activities, (2) pick-up mode is introduced explicitly considering two persons' prism constraints, and (3) multi-day activity-travel patterns can be considered. Initial application of SMAP was to understand the elderly household activity-travel patterns and responses to changes in conditions. By conducting interactive in-depth interview surveys with this tool, various individual and household specific constraints were explored and the possible new activity patterns to the changes of constraints were examined considering pick-up mode and multi-day activities. GIS advantages were effectively used to conduct this enhanced gaming simulation technique.

There would be a wide range of application fields of SMAP other than this study of activity analysis of the elderly household, making use of GIS-based gaming simulation techniques. Especially, it would be useful to analyze such as inter-household car-pooling behavior considering activity scheduling of more than one person and travel blending introducing trade-offs of multi-day activities. Detailed travel data including routes and speeds collected using positioning technologies (Global Positioning System (GPS) and PHS) could also contribute to gaming simulation techniques, for example, responses of travelers after pricing measures could be well understood on GIS. For these applications, it would be useful that alternative activity pattern generator should be improved in choice set dimensions introducing location and route choice.

Another direction is application of SMAP to decision making support system of activity planning. Although in the present study, SMAP models only choice set and lacks in choice models from the choice set, there is a possibility of further development like GISICAS introducing models of activity pattern generation. Users of this system would be able to evaluate their activity-travel patterns from the viewpoints not only of travel time and travel cost but also of personal physic2al energy consumption and environmental damages, etc. Recommended activity-travel patterns are demonstrated according to individual specific objective functions, being really the aid for individual "activity planning".

The behavioral analysis in space-time based on the activity-based approach is very useful in order to understand activity-travel behavior, but data collection of household activity patterns, transport networks and activity opportunities are critical elements for the study. For data on travel behavior, use of positioning technologies such as GPS and PHS could improve quality of diary data and mitigate the burden of respondents. For transport network and opportunities, GIS database available for researchers need *Simulation Model for* to be prepared and updated periodically.

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., E. Hato, T. Daito and A. Tanabe (2000). Monitoring travel behaviour using PHS based location data, *Journal of Infrastructure Planning and Management*, No.653/IV-48, 95-104. (in Japanese)

Bowman, J. L. and M. Ben-Akiva (1996). Activity based travel forecasting, *Paper prepared for a TMIP Conference on Activity Based Travel Forecasting*, New Orleans, Louisiana June 2-5.

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.

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. (1980). Experience with Household Activity-Travel Simulator (HATS), *Transportation Research Record*, 765, 6-12.

Jones, P. M., Dix, M. C., Clarke, M. I. and Heggie, I. G. (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: *Activity-Based Approaches to Travel Analysis* (Ettema, D. F. and H. J. P. Timmermans, ed.), pp.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*, 30(3), 191-216.

Landau, U., J. N. Prashker and B. Alpern (1982). Evaluation of activity constrained choice sets to shopping destination choice modelling, *Transportation Research*, 16A(3), 199-207.

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: *Timing Space and Spacing Time 2, Human Activity and Time Geography* (Carlstein, T., D. Parks and N. Thrift. ed.), pp.162-180, Edward 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.

Nitta, Y., A. Mioshi and Y. Mori (1995). Basic study on special bus service planning for improving mobility of elderly, *Journal of Infrastracture Planning and Management*, No.518 IV-28, 55-67. (in Japanese)

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., 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 (1998). A study on accessibility of aged people considering daily activity pattern – A case study in Akita city, *Infrastructure Planning Review*, 15, 671-678. (in Japanese)

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

Recker, W. W. (1995). The household activity pattern problem: General formulation and solution, *Transportation Research*, 29B(1), 61-77.

Thill, J. -C. and J. L. Horowitz (1997). Modelling non-work destination choices with choice sets defined by travel-time constraints. In: *Recent Developments in Spatial Analysis: Spatial Statistics, Behavioural Modelling, and Computational Intelligence* (Fischer, M. M. and A. Getis, ed.), pp.186-208. Springer, Heidelberg.