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STOCHASTIC SIMULATION OF THE TEMPORAL AND SPATIAL INTERACTIONS IN URBAN TRAVEL

Ryuichi Kitamura and Tenny N. Lam
Department of Civil Engineering
University of California, Davis
Davis, California 95616

Masahiro Hioki
Takenaka Komuten Co., Ltd.
Tokyo, Japan

The patterns of urban travel are influenced by the interactions between four fundamental elements. Two of the elements are related to the individual traveler: time budget and activity pattern. The other two elements are related to the urban system: land use and transportation. These elements interact with each other within a framework of space and time. Based on a time dependent markov renewal model of trip chaining, it is possible to simulate the many properties of the constrained activity paths in space and time. Through the stochastic processes in the model, the interrelationships between travel movements and urban structures can be simulated and examined.

1. INTRODUCTION

Time and space are fundamental in shaping the life style of people and consequentially, the patterns of urban travel and spatial locations. The rich variety and large number of activities available in an urban area necessitate spatial separation and locational specialization. In the pursuit of daily activities, a person must define his activity needs and time budget. Given the activity requirements and the time constraints, there is considerable flexibility and freedom in choosing the locations for the activities, sequencing and scheduling the order of activities, and choosing the transportation modes. A set of spatial paths is required to link the successive activity locations. Since travel inevitably requires time, the spatial paths must also move forward along the time dimension. Likewise, time is consumed while a person is engaged in an activity. Within a framework of geographic space and time a person's itinerary and log of activities can be plotted in the form of a continuous trajectory. Figure 1 is an example of such a depiction. In the example, an individual leaves home, visits a store along the way to the bank, and then returns home. A sloping line is the travel segment between two activity locations. A vertical line represents the time the person spends at that location for one or more activities. In travel and activity analyses, which are essential for urban land use and transportation planning, the most intriguing and complex aspect is to understand the way a person chooses his activity and travel paths in space and time. As one moves along the trajectory, every point presents different travel environment and personal circumstance. The dynamic interactions between travel behavior and its environment is a central subject in travel demand analysis.

The time/space trajectories describing the movements of people are constrained (Hagerstrand, 1970) and must be continuous. These two aspects must be incorporated into the analysis of travel behavior when both time and space dimensions are considered. The travel behavior and the time/space paths are constrained by three different sets of factors:

a) time budget dictated by basic physiological and other human needs (sleeping, eating, work and personal care),
b) spatial accessibility limited by the speed of travel means and the time budget available to travel,

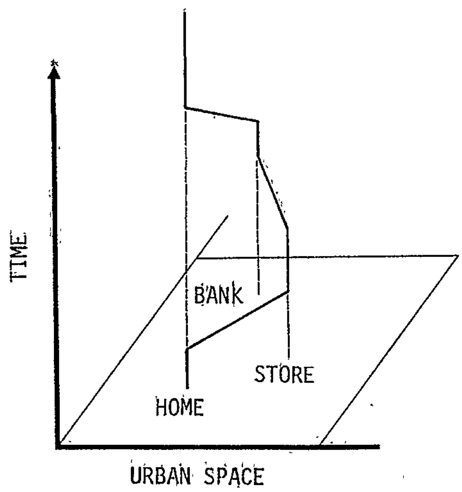

Figure 1. An example of a movement and activity trajectory in time and space.

c) time-of-day dependencies of the activities as determined by social custom and institutional rules.

The existence of a department store for shopping, for example, is dependent on the store's business hours. Governed by the constraints, the time/space paths in the form depicted in Figure 1 are contained within prism shaped time/space domains. The prisms reflect the strong coupling of the temporal and spatial dependencies between successive activities on the trajectories. The dependencies arise from the facts that a person cannot be simultaneouly at two or places at the same time, travel always consumes time, every activity has a time requirement, and every point along the time/space path is rooted in the past history (Hagerstrand, 1975; Burns, 1979).

The interaction between urban travel and the environment (land use, transportation, personal circumstances, and institutional factors) play a very important role in urban travel demand. When travel behavior is considered in temporal as well as spatial contexts, it becomes necessary to redefine the land use patterns in terms of spatially and temporally distributed opportunities for various types of human activities, such as work, shopping, social, business, recreation, etc. For example, a department store as a shopping opportunity must depend on its location and business hours. The traveler must then superimpose his personal needs, his relative location at the time he wishes to go shopping, his time budget, and his other activity plans in choosing the need, the time and the store location of his shopping. In spite of the importance of the time element on travel behavior, little has been developed to model in both time and space dimensions. Most often, the trajectories of the daily movements of the urban residents are collected over some time interval and only the spatial aspects are analyzed in travel studies. On the other hand, in activity analysis, the spatial dimension is ignored.

It is well documented that activity patterns exhibit clear temporal rhythms (e.g. Shapcott and Steadman, 1978). It is also widely acknowledged that most urban transportation problems are related to surges in demand in time and space, such as congestion and unbalanced directional traffic flow. Recent transportation improvement measures have placed increasing emphasis on managing the spatial and temporal distribution of demand, for example, work shift and hour management, road pricing, and traffic diversions. Urban planning has given much attention to redistributing urban densities (such as urban infilling). It is ironical that there is no readily available quantitative tools for understanding the impacts of these planning measures on the temporal and spatial distribution of travel demand.

Many stochastic models have been developed for either the temporal aspects or the spatial aspects of travel and activity analyses (e.g. Damm and Lerman, 1981; Kitamura and Lam, 1981; Kitamura, 1983.1). However, it is difficult to combine the time and space aspects in an analytical model. This study presents an attempt to develop a time dependent stochastic simulation model of the time/space paths. The objective is to show that both time and space dimensions are simultaneously important to understanding travel behavior and activity scheduling. The study shows that there are significant issues related to urban planning that can only be understood by studying the time/space paths. The simulation model illustrates a number of important interactions between land use and transportation with respect to the travel patterns. The study also shows the flexibility of the simulation model as a tool for simpifying the complex nature of the interactions.

2. THE STOCHASTIC ACTIVITY AND TRAVEL PROCESSES

If the activity and travel diary of each urban resident is known and represented in the form of trajectories such as the one shown in Figure 1, many typical transportation studies can be carried out by properly analyzing a collection of the trajectories. For example, traffic counts and traffic densities may be obtained by counting the number of lines passing through a spatial point (or over a small area) over a time interval. The projection of the trajectories onto an urban space by ignoring the time dimension gives the desire line diagram commonly used in transportation planning. The statistical analysis of the trajectories projected onto the time domain, with an added axis for the enumeration of the sequence of activities and/or trips would form the basis of what is called "trip chaining" analysis. Since urban travel is simply a collection of all the movements made by people in their pursuit of activities, most urban travel and activity studies can be effectively carried out with the trajectories defined in the multidimensional space of time, location, and activity.

Activity and travel patterns can be visualized as stochastic processes in many ways within a general framework of time/space trajectories. In the most general form, the trajectory can be approximated by specifying (discrete) "states" of the trajectory and the time when each of the states is entered. A state may be defined by an activity category, or further by the spatial location where the activity takes place. This view is shown schematically in Figure 2. Let X_n be the n-th state of an individual's trajectory (the n-th activity of the day, for example), and T_n be the time when X_n was entered. When the X's are defined by the activity categories, the process $(X,T)=(X_n,T_n;$ $n=0, 1, \ldots)$ represents an individual's activity diary, from which the time allocation among activities can be retrieved. When the X's are defined both by activity and location, the spatial element is introduced into the process by assuming that an urban area can be appropriately represented by a set of discrete zones. More elaborate definition of the states is possible from more detailed description of the trajectories. For example, the state may be defined by the activity and its location, mode of travel, land use at the activity site, etc.

The typical trajectory of a person starts at home, possibly leaving home during the day to pursue out-of-home activities and then returning home some time within the same day or early next morning. Such a (spatially) closed trajectory is called a "time-space activity chain." Closely related to the time/space activity chain is a "trip chain," which is a spatially closed series of trips that begins and ends at the same location or activity, such as "home". A trip chain involves at least one "sojourn" for out-of-home activity. Furthermore, an individual may make one or more trip chains in a given day, or may not make any at all. There may be more than one pattern of trip chaining, even when the types, sequence, and durations of out-of-home-activities are specified. For example, one may have a single trip chain with multiple-sojourns or several separate trip chains each of which involves only one sojourn. Therefore, trip chaining is a concept associated with a collection of the segments of a trjectory, while activity chaining represents a trajectory in its entirety.

The model used here integrates the three elements in temporal activity chain analysis: activity linkage, activity occurrence time, and activity duration (Kitamura and Lam, 1981). By integrating the concepts of activity linkage and occurrence time, the model gives a representation of the cruicial time dependency of activity linkage. The time dependent activity linkage is described by the con-

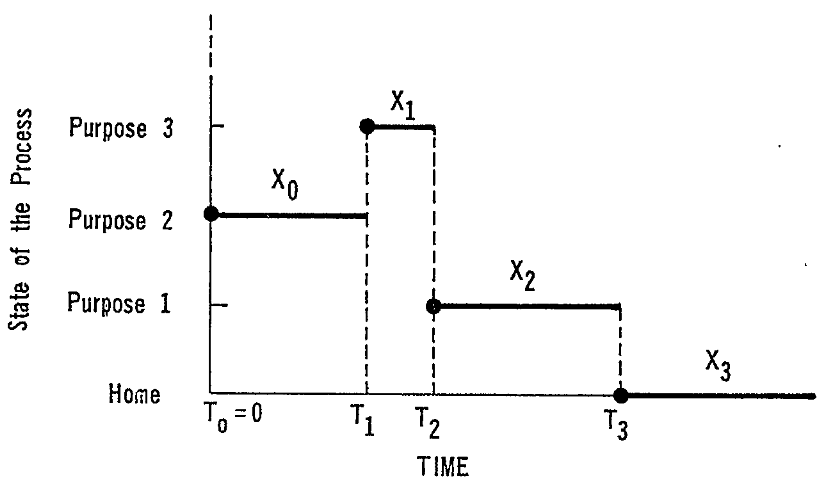

Figure 2. A trajectory expressed as a process (X, T) over a state space along the time axis.

ditional transition probability underlying the (X,T) process:

$$\begin{aligned} &\Pr(X_{n+1}=j \mid X_n=i,\ T_n=s,\ T_{n+1}=t) \\ &=\Pr(X_{n+1}=j \mid X_n=i,\ T_{n+1}=t) \qquad (1) \\ &=p(i,j,t), \qquad t \geq 0 \end{aligned}$$

where time (t and s) is defined in terms of the time-of-day. Similar to the Markov renewal process, it is assumed that the probability is conditionally independent of the history of the process, except for the immediately previous state. Namely, the probability that the state of the next visit is j depends only on the present state ($X_n=i$), the time when the present state is entered ($T_n=s$). It is reasonable to assume that a person would normally leave an activity site when the activity is completed. At that point in time this person would decide on what to pursue next, or would move on to the next planned activity. The time of activity completion ($T_{n+1}=t$) obviously affects the transition to the next activity more than the starting time of the activity just completed (T_n). Therefore, the process can be simplified to depend only on T_{n+1}. As a result, the transition probability is represented by the distribution p(i,j,t). An examination of a series of hypotheses with data indicates that this simple representation is adequate and best explains activity choice behavior (Kitamura and Kermanshah, 1983).

Next, the probability that governs the duration of an activity can be specified as follows:

$$\begin{aligned} &\Pr(T_{n+1} \leq t \mid X_n= i,\ T_n= s),\ t \geq s \geq 0 \\ &=\Pr(T_{n+1} - T_n \leq t - s \mid X_n = i) \qquad (2) \\ &=F_i(t - s). \end{aligned}$$

In activity chaining , the assumption that an activity duration is statistically independent of its starting time appears to be intuitively acceptable. For example, one needs a minimum amount of time to eat lunch regardless of the exact time when he enters a restaurant. However, there are many situations that the sojourn time distributions are obviously time dependent. For example, travel time during various parts of the day is not the same due to traffic congestion or bus schedule. The queueing and waiting time at the checkout counter is significantly different at the supermarket during various hours. Long appointments are arranged usually for the early part of the day and long leisure activities are arranged more likely for the evenings. The sojourn time distribution may be alternatively defined as time dependent. In this study the sojourn time distribution F_i is assumed to be time homogeneous, although the time dependent distribution does not add any conceptual or theoretical difficulties to the simulation.

The two elements, p(i,j,t) and $F_i(y)$, are the key components that completely determine the process. They also have clear interpretations in the context of activity chaining. The sojourn time distribution, $F_i(y)$, correponds to activity duration (plus travel time when appropriate), which is assumed to vary with the activity. The conditional transitional probability, p(i,j,t), represents the concept of time dependent activity linkages. The component p(i,j,t) is where activity choice and the decision environment interface. During time periods when a large number of activity opportunities are available, the probability for activity engagement is naturally higher. On the other hand, certain activities are not available during certain time periods of the day; and there would be a smaller transition probability for these activities. Thus the term p(i,j,t) offers a mechanism for dealing with such factors of reality and the time dependent nature inherent in human behavior.

Specification of p(i,j,t) and $F_i(y)$ of course has to be consistent with the properties that constrain movements in time and space, as well as with known travel behavior. Embedded in the activity chaining process are many concepts such as time budgeting, out-of-home activity choice, locational choice and spatial interaction. Each of these elements is dependent on time. The fact that most people return home and retire by the end of the day typically illustrates the time dependency of activity choice and travel patterns. For example, it was shown that the conditional probability of returning home is a positive exponential function of time (Kitamura, Kostyniuk and Uyeno, 1981). Personal circumstances, such as life cycle and other socioeconomic factors, also play an important role in affecting travel choice and activity patterns (Kitamura, 1981 and 1983.3; Kostyniuk and Kitamura, 1981, 1982.1 and 1982.2). Considerable attempt has been given to time use (e.g. Allaman et al, 1981) with an objective to better understand the mechanism of activity choice and time allocation. A model of discrete activity choice and continuous time allocation gave a strong support to the premise of random utility maximization in activity patterns (Kitamura, 1983.2). The supply of activity opportunities also varies depending upon the time of day, day of week, and location. The service level of transportation systems is again dependent on time. A typical example is transit services and traffic congestion.

Although few of these aspects are incorporated into the simulation reported here, a number of the properties of the spatial choice constrained paths are represented in the transition probability, p(i,j,t):

a) for out-of-home destinations, the transition probability increases with the attractiveness of the destination,

b) for out-of-home destinations, the transition probability from i to j decreases with the spatial separation between i and j,

c) the probability of returning home increases with time-of-day,

d) the probability of returning home increases with the spatial separation of the present location from home,

e) the transition probability from i to j, both i and j are out-of-home states, decreases with time-of-day,

f) the transition proability from i to j, both i and j are out-of-home states, decreases with the time or distance from i to j and then returning home.

Conditions a) and b) are axioms of spatial interaction. In a recent study, the concept of intervening opportunities has been used together with utilitarian assumptions of travel decision (Kitamura, 1983.4). In another study (Kitamura, 1983.1), destination choice was modeled with the concept of "prospective utility". Both studies show that destination choice is in fact future dependent and therefore, choices in an activity chain are interdependent. Conditions c) and d) has been illustrated (Kitamura, Kostyniuk and Uyeno, 1981) for the case of a uniform linear city. The same framework is used to derive conditions e) and f). Since the path is constrained within a prism, the time available for activity at a location decreases as time progresses and as the distance between the location and home increases. If it is assumed that an individual will not visit the location if the time available there is not enough for the intended activity, then the probability of the visit decreases with the time and distance from home.

The time constraint placed on activity and travel has also been focused in many recent studies (Damm, 1980; Becker, 1965; Hummon, 1979; Kitamura and Lam, 1983). The effects of perceived value of time on modal split and travel have long been actively pursued in transportation research. The spatial and temporal interactions in terms of accessibility to opportunities and their effects on trip making, travel, time allocation and activity choice have been theoretically examined by Burns (1979). However, the cumulative time span spent on a sequence of trips and activities may affect the occurrence times of future trips and activities. The interaction between activity (and/or trip) durations, the temporal structure of urban activities, and the rhythmic patterns of daily activities further complicates many of the behavioral questions important to travel demand forecasting (Lerman, 1979).

A possible structure of $p(i,j,t)$ is

$$p(i,j,t)=P_{ij}(t)=Q_{ij}g(t,d_{ij},d_{jh}), \qquad (3)$$

where Q_{ij} represents the intensity of spatial interaction between i and j which would be expected if the movement were not constrained. The function g represents the temporal and locational aspects of the constraints imposed. As Q_{ij}, we may use a gravity model or any other spatial interaction models.

Fewer guidelines are available for the specification of the function g. In the present formulation, it is assumed that the function represents only the time constraints imposed, which depends on the time of transition and the present location i, alternative location of the next visit j, and home, h. Suppose that the probability that location j is visited decreases with the time available at that location. Suppose T represents the time budget constraint by which the individual must return home. Then the latest time at which the individual can leave location j is $T-d_{jh}$. If the time when the sojourn at the present location i ends is t and the time required to reach j is d_{ij}, then the maximum time available at j is $T-t-d_{ij}-d_{jh}$, if this quantity is nonnegative. Now suppose that the probability that the individual chooses this location is proportional to the probability that the above time available is large enough to pursue an intended activity at the location. Let y be the time requirement for the activity. Then, we may define g as the probability that the available time $T-t-d_{ij}-d_{jh}$ is no less than y. Since the activity time depends on the microscopic nature of the activity, we may assume it as a random variable. Let G be the distribution of y. Then,

$$\begin{aligned} g(t,\ d_{ij},\ d_{jh}) &= Pr(y< T-t-d_{ij}-d_{jh}) \\ &= G(T-t-d_{ij}-d_{jh}). \qquad (4) \end{aligned}$$

At this point no information is available as to the actual form of this distribution function.

3. THE SIMULATION MODEL

The parameters and mathematical forms of the various processes in the simulation model are summarized in Table 1. The intensity of spatial interation between zones, Q_{ij}, is expressed in a multinomial logit form and is a function of the attraction measure A_j, the travel time between zone i and zone j, and a parameter Θ. This term gives the probability that zone j will be chosen by a trip maker located at i given that he will continue on out-of-home activities. The probability that a trip maker who completed a stay at i at time t will choose zone j is expressed as $P_{ij}(t)$ given in Eq. 3. The parameters a and b are both positive and the term takes on a larger value as t, d_{ij}, or d_{jh} increases.

TABLE 1

FUNCTIONAL RELATIONSHIPS USED IN THE SIMULATION EXPERIMENT

A. Probability that zone j will be chosen by the trip maker at i, given that he continues on with out-of-home activities:

$$Q_{ij} = \exp(A_j - \theta d_{ij}) / \sum_{k \neq h} \exp(A_k - \theta d_{ij}), \ j \neq h \qquad (5)$$

B. Probability that the trip maker at i will move to j after completing a stay at i at time t:

$$P_{ij}(t) = Q_{ij} / [1 + \exp\{-a(b - t - d_{ij} - d_{jh})\}] \quad , \ j \neq h \qquad (6)$$

C. Probability that the trip maker will return home temporarily after completing a stay at i at time t:

$$P_{ih}(t) = [1 - \sum_{j \neq h} P_{ij}(t)] \quad [1 - \exp\{-k(T - t - d_{ih})\}] \ , \qquad (7)$$

$$t + d_{ih} \leq T$$

D. Probability that the trip maker will return home permanently after completing a stay at i at time t:

$$P_{ih}*(t) = [1 - \sum_{j \neq h} P_{ij}(t)] \ \exp\{k(t + d_{ih} - T)\} \quad , \qquad (8)$$

$$t + d_{ih} \leq T$$

E. Distribution of sojourn durations, w:

$$f(x) = dPr(x < w \leq x + dx) = (2/q)^2 x \ e^{-2x/q}, \ x \geq 0 \quad (9)$$

where q is the mean that depends on the activity type.

Accordingly, $P_{ij}(t)$ decreases with them and out-of-home engagement becomes less likely as time proceeds, as the origin-destination travel time increases, or as destination-to-home travel time increases. Note that the rate of this decrease is not linear to time. Inspection of Eq. 6 shows that it is a logistic function multiplied by Q_{ij}. As a result, it is possible to represent different patterns of time-of-day dependency of activity engagement by changing the values of the parameters a and b. The travel time variables d_{ij} and d_{jh}, are included here to reflect more accurately the time constraint imposed on the movement pattern.

The probability of returning home is defined as one minus the sum of the probabilities of out-of-home activity engagement $(P_{ij}(t))$ in all zones. In the simulation, different activities are assigned to different zones. A portion of the trip makers who returned home is assumed to have completed their daily out-of-home activity schedule. This portion is determined by an exponential function of the time remained before the time budget is exhausted, $(T-t-d_{ih})$. As the time remaining before the exhaustion approaches zero, the probability of out-of-home activity termination approaches unity. If the return to home is temporary, the trip maker will leave home again and engage in additional out-of-home activities.

The urban structure is expressed in the simulation experiment by the zonal attraction measure A_j, interzonal travel time d_{ij}, and the location of the residence zone h. The transportation level of service is represented by the interzonal travel time, which is determined as a product of the zone-to-zone network distance and a parameter DT. The distance between two adjacent zones is set to be equal to 1, and DT represents the travel time between these two zones. It is assumed that the transportation network in the hypothetical city consists of the links that connect directly every pair of adjacent zones (see Figure 3). The zone-to-zone travel time is measured along the shortest path of the network. The sensitivity of destination choice behavior to travel time is represented by parameter θ, which takes on the value of 0.25 in the experiment.

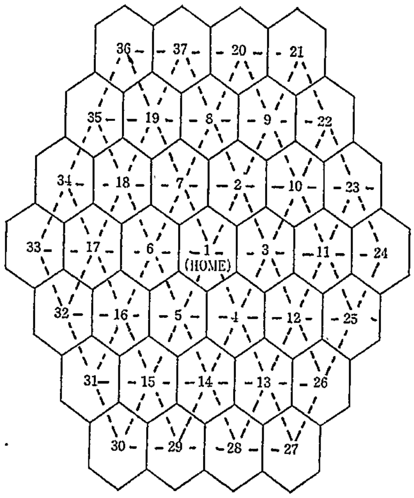

Figure 3. The hypothetical city and its transportation network (dashed lines) used in the simulation experiment.

The duration of a stay in a zone (sojourn duration) is assumed to have an Erlang type 2 distribution. The mean duration is 120 minutes for all out-of-home states and 300 minutes for the home state. Zone 1 is where the home of the trip maker is located in the base case. It is also assumed to contain opportunities for out-of-home activities. In the simulation experiment, the trip maker leaves home at time 0. This simplification is useful because it makes the interpretation of the simulation results more straightforward. In each run of the simulation experiment, the trip maker's movement in the hypothetical city is randomly generated along the time dimension using the relationships of the time dependent zone-to-zone transition probabilities and sojourn durations as defined in Table 1. When the time budget constant, T, is not satisfied by a movement pattern thus generated, the same process is repeated until a pattern contained within the time budget is obtained.

Table 2 summarizes the parameter values for the "base case" simulation, which is used as the norm for comparison of results. The ranges of other parameter values used in the experiment are also given in the table. Each simulation run is carried out until 5,000 complete movement patterns are obtained. The variations in the travel pattern indices obtained from simulation runs are examined using the base case parameter values by executing four runs with different seeds for the random number generator. Examination of the averages of trips per trip maker, number of chains, out-of-home time, and total travel time indicated that for all indices except total travel time, the ratios of the standard errors to means were less than 1%. For total travel time, the ratio was less than 1.62%. The small variations across the simulation runs are indicative of the adequacy of the sample size of 5,000 patterns in interpreting the simulation results.

4. SIMULATION RESULTS

The travel pattern in the hypothetical city is summarized in terms of the average number of trips per trip maker, average number of trip chains, average number of stops in a trip chain, average time spent out-of-home, total travel time, and average distance traveled in a trip. Figure 4 shows the sensitivities of these indices to changes in the unit travel time DT between two adjacent zones in the range of 2.5 minutes to 40 minutes. Intrazonal travel time is assumed to be 70% of the travel time between the adjacent zones. The figure shows that the total travel time and the mean trip distance are very sensitive to the travel time parameter DT. The mean trip distance decreases very rapidly as the unit travel time increases. The total travel time shows a unimodal pattern with a minimum around the base case which has a value of 10 minutes for

TABLE 2

PARAMETER VALUES USED IN THE SIMULATION EXPERIMENTS

<u>BASE CASE</u>

Uniform City, Home in Zone 1

$A_j = 3.40$	DT = 10
a = 0.001	b = 720
k = 0.25	T = 720

$$q = \begin{cases} 120, & \text{out-of-home activity} \\ 300, & \text{in-home activity} \end{cases}$$

$\theta = 0.25$

<u>ALTERNATE CASES</u>

Urban structure: i) Uniform, Home at Center*
ii) Uniform, Home at Fringe
iii) With Activity Centers (A_j=3.80), Home at Fringe

Travel time: DT = 2.5, 5, 10*, 15, 20, 40

(a,b,k) = (0.001, 720, 0.25)*
(0.005, 720, 0.25)
(0.005, 120, 0.25)

Time budget: T = 720*, 360

* - Indicates base case values

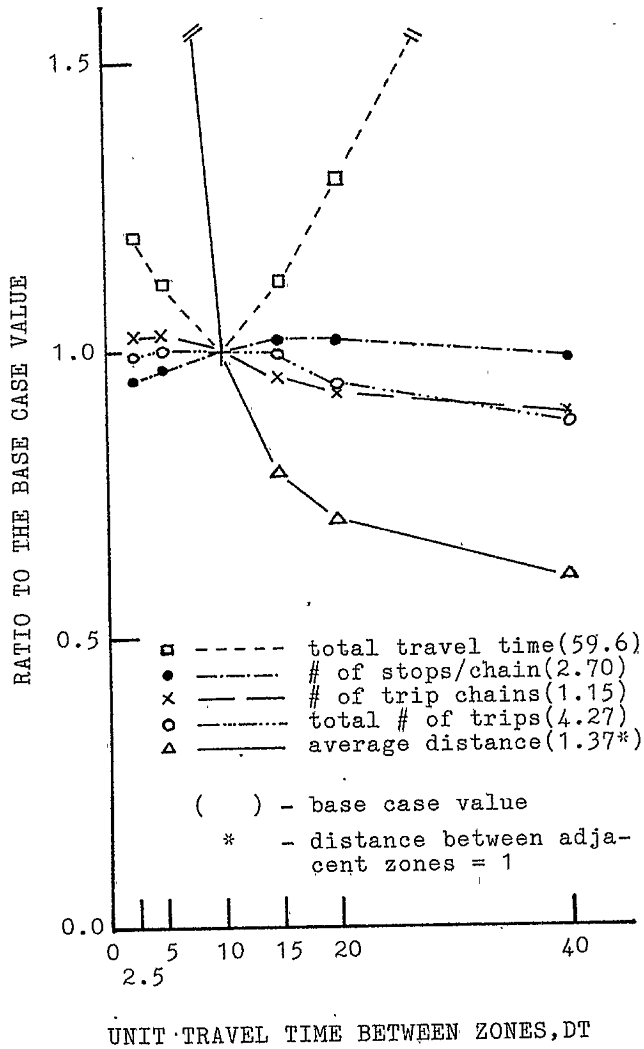

Figure 4. Various travel pattern indicators presented as ratios to the base case for different values of the travel time parameter, DT (base case: DT=10).

In comparison, the number of trips, trip chains and stops/chain do not vary as much as the changes in DT. This is a result of the model assumption that the probability of the trip maker continuing with out-of-home activities or returning home is primarily a function of the time-of-day. Since this group of base case simulation allows a time budget T of 720 minutes and this value is large compared to the typical trip time, the trip maker shifts his destination preferences as the unit travel time (reciprocal of the travel speed) changes but maintains about the same level of activity.

Table 3 summarizes the effects of the time budget constraint (T) and the residential location relative to zones containing activity opportunities. When the time budget is reduced in half to 360 minutes, the number of trips shows a decrease of about 35% and the average number of stops per trip chain is also reduced by 35%. These reductions are less than the percentage in the reduction of the time budget. On the other hand, the total out-of-home time is decreased by 50%. It is worthy to note that the average trip length shows a reduction of only about 20%, indicating that according to the behavioral mechanism assumed in the simulation model, adjustments to a tight time budget are made in both the number of activities and the trip length.

Figure 5 shows spatial distribution of activity locations for three different levels of travel time (DT= 5, 10, and 20) and two levels of time budget (T= 720 and 360). Also shown is the case where the destination choice probabilities are obtained directly from Q_{ij} in Table 1. This is the "home-based destination choice probability" when i is the home base. This set of probabilities represents the spatial distribution of activity locations that would be obtained if the trip makers always return home after one stop outside the home. In other words, there is no consolidation of trips into trip chains. The activity locations are represented by a set of rings, each of which is a subset of the zones that lie at the same distance away from the home zone. The closest one, which is the home zone itself, is called ring 1, the ones immediately adjacent to the home zone form ring 2, etc. The figure clearly shows that the activity locations tend to concentrate around the home base as the time budget is tightened. The centroid of the activity locations lies farther away from home when the time budget constraint is relaxed. This is the case for all levels of unit travel time DT. It is noted that, even with the tighter time budget, the activity locations tend to be farther from home than the home-based destination choice probability would indicate. This reflects the effect of trip chaining and the resulting non-home based trips on the spatial distribution of activity locations. It is

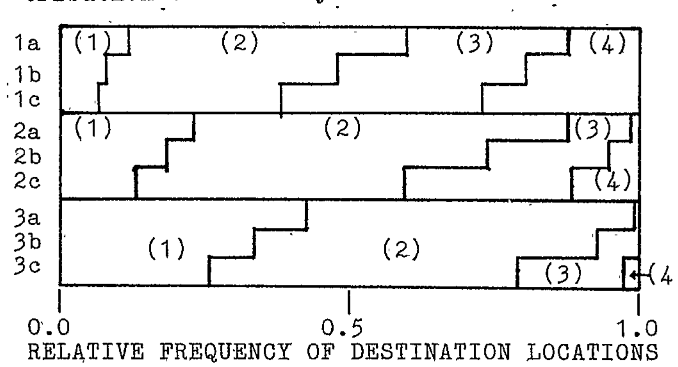

Figure 5. Distribution of activity locations for the base case for different unit travel time (1: DT=5;2:DT=10;3:DT=20) and time budget (a:Q_{ij};b:T=360;c:T=720).

TABLE 3

A COMPARISON OF SOME SIMULATION RESULTS

	BASE CASE T=720 City A	TIME BUDGET CONSTRAINED T=360 City A	FRINGE HOME LOCATION T=720 City B
Average no. of trips	4.267	2.764	4.709
Avg. no. of trip chains	1.154	1.003	1.525
Avg. no. of stops/chain	2.696	1.755	2.088
Total out-of-home time	434.9	219.4	403.7
Total travel time	59.6	31.8	45.1
Average trip length*	1.40	1.15	0.96

* distance between adjacent zones = 1

also noted that the figure clearly shows the effect of the unit travel time DT on the spatial distribution of activity locations at both levels of time budget constraint.

Returning to Table 3, the last column shows the effects of the relative home location on the travel patterns. In the base case, the home zone is at the center of the 37 zone hypothetical city. In the other case, it is located at one of the fringe zones of a 30 zone city. Referring to Figure 3, which represents the base case, the fringe experiment put the home in zone 33 and removed zones 21-27. Other than the location of the home zone and the number of zones, all the other parameters are the same as in the base case (given in Table 2). We refer to the base case as city A and the fringe home location case as city B. Comparing the first and third columns in Table 3, there are substantial differences in all the indicators between the two cases. The increased number of trips and trip chains and the decreased average trip distance for the fringe case are particularly notable.

The effect of the residence location on the spatial distribution of activity locations can be seen in Figure 6. In both cases, the city is assumed to be uniform

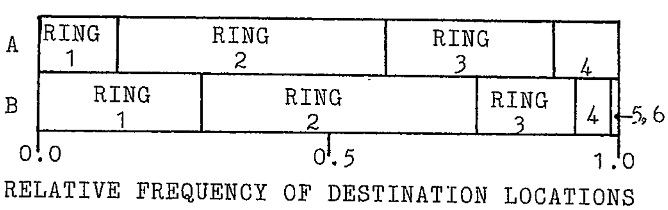

Figure 6. A comparison of the spatial distribution of activity locations between city A with a central home location and city B with a fringe location.

in terms of the attraction measure. For the two simulation cases shown, the base case parameter values were used (a time budget T=720 minutes and unit travel time DT=10 minutes between adjacent zones). For city A with the central home location, the home is surrounded by 6 adjacent zones containing activity opportunities and there are 12 zones reachable within 20 minutes. For city B with the fringe home location, there are only 3 immediately adjacent zones and 5 zones reachable with 20 minutes. The fringe location pattern obviously is affected by lesser activity opportunities within a given distance from home. While there are still a large number of activity opportunities available for the fringe residents, these opportunities are less attractive because they are farther. The result is the concentration of activity locations around the home base as shown in Figure 6 by the larger fraction of ring 1 destination choices.

The relaionship between the level of out-of-home activity participation and travel pattern is examined by changing the values of the parameters a and b. Figure 7 summarizes the results together with the parameters. As expected, the number of trips increase as the participation level increases, i.e. as the level of $P_{ij}(t)$ increases for non-home locations. Quite unexpected is the decrease in the average trip distance and the number of trip chains that accompany the increased activity level. It is due to the tendency that when the participation level is high, the trip maker tends to pursue many activities before returning home; thus a tendency to have fewer trip chains but with more stops per chain. The decrease in the trip distance reflects the adjustment made by the trip maker between the activity time and travel time, i.e. in order to visit many destinations within a time budget , the travel time must be reduced as a necessity and as a result of the circumstance to be able to consolidate and combine many activities on the same trip chain.

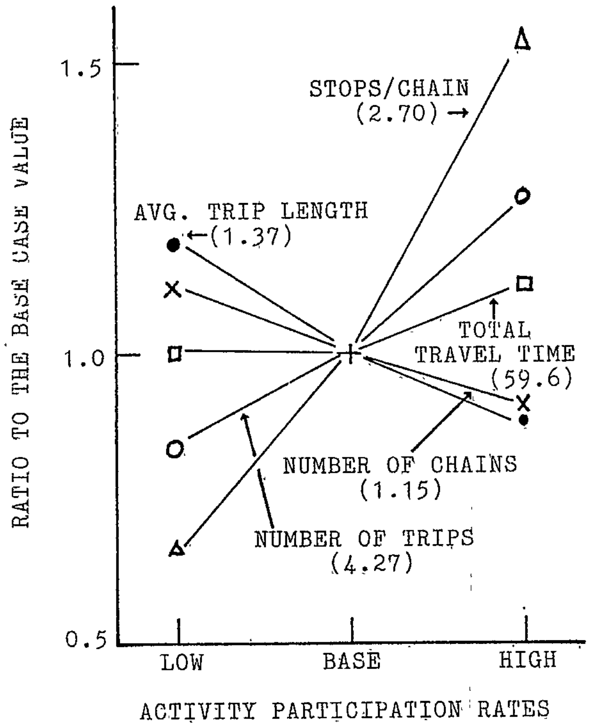

Figure 7. Various travel pattern indicators presented as ratios to the base case for different levels of activity participation. The values of a and b for the low, base, and high levels are (0.005,120), (0.01, 720) and (0.05 and 720), respectively.

The decrease in the average trip distance observed with the increase in activity participation level does not imply that the trip maker pursued their activity in the vincinity of the home location. A comparison of the spatial distribution of activity locations across the three cases indicate that the frequency of destinations in ring 4 increases as the participation level increases, while those in rings 1 and 2 decreases. The simulation runs are for the base case city with the home in the center. Together with the decreasing trip distance as a result of increasing participation levels, the result implies that the trip maker makes many short trips and stops at farther locations in multiple-stop trip chains when the activity participation rate is high.

The effects of activity centers on out-of-home activity participation level and spatial distribution of activity locations are examined by the introduction of two activity centers at various zonal locations with a value of A_j twice as large as that for the activity in other zones. The two centers are arranged in two adjacent zones, one closer to the home zone than the other. The simulations are based on city B with a fringe home location. The analysis indicated that the impacts of the activity centers on the number of trips, trip chains and total out-of-home time are rather small. Naturally the spatial distribution of activity locations is strongly affected by the activity center locations and so is the mean trip length. Figure 8 summarizes the distribution of activity locations for various locations of the activity centers. The experiment included four runs with activity centers at different locations. The run without activity centers is also presented.

The effect of the activity center on the spatial distribution of activity locations is evident from Figure 8. When the centers are located closest to the home zone (zones 3 & 7 case), most of the activities pursued are in the activity center zones. Further inspection of the movement patterns indicated that the only non-home-based origin-destination flow that is increased after the introduction of the activity centers is the flow between the two activity center zones. This effect wears off gradually as the distance between the centers and the home zone increases and the pattern approaches the case without the activity centers.

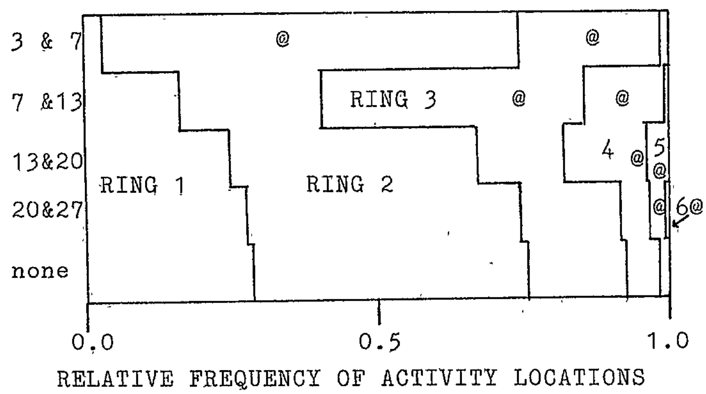

Figure 8. A comparison of the distribution of activity locations for various locations of the activity centers, whose zone nos. are indicated on the side. The symbol @ denotes the ring containing the activity center.

5. SUMMARY

A stochastic simulation model of the time and spatial interactions between personal activity needs and constraints and the urban environment has been developed and presented here. A number of simulation experiments have been carried out with hypothetical parameter values and a hypothetical city. The results of the experiments indicate the sensitivity of the model to changes in the input values. Although the model is yet to be calibrated and experiments with real world data have not been carried out, the simulation runs suggest the usefulness and flexibility of the model for real world applications.

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