A TECHNIQUE FOR INCORPORATING THE EFFECT OF CHANGING PATTERNS OF TRAVEL BEHAVIOUR INTO THE TRADITIONAL TRANSPORT PLANNING PARADIGM

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abstract: Changes in society and the socio-economic and demographic characteristics of urban populations are affecting activity and travel patterns. The resulting trends in transport demand are highly significant but in traditional transport planning models, there are no explicit mechanisms for representing links between activities nor long term trends in the underlying activity pattern. This paper proposes a model based on using Markov chains to represent large-scale patterns in travel behaviour. The model provides a simple and practical technique for extending the traditional transport planning paradigm to include the effect of social trends and their impact on the pattern of travel demand.

1. INTRODUCTION

When the results of recent studies of urban travel characteristics are compared with similar surveys from the 1970s and earlier, it is clear that there have been significant changes in the number and types of trips being made by private car. Some of the significant trends are

- decreasing significance of work trips
- increasing importance of leisure trips
- increasing importance of trips made for chauffeuring children and old people, and for other family reasons
- increasing propensity to link trips into chains which involve several trip purposes
- increasing participation rate in private motorised transport by all sectors of the community but especially by women and older persons
- differences in the trip making patterns of males and females
- increasing number of trips per day by each person.

These trends are reflected in the breakdown of trip purposes for travel in Australian cities, as shown in Table 1. To a large extent, the trends in trip characteristics can be explained in terms of changes in society and the socio-economic and demographic characteristics of urban populations. Increasing wealth, changes in the nature of work and pattern of employment, changes in age profile of the population, increased status of women, and increased participation by women in the workforce are some of the factors that are being reflected in urban travel behaviour. As recognition of the importance of social trends grows, the link between social trends and transport activity is becoming an increasingly important research topic (Richardson et al, 1996; Morris et al, 1996).

Table 1: Trip Purpose by People of Working Age (Australia: Persons 20-65 years: 1986)

Purpose	Male	Female
Work	22%	11%
Education	4%	5%
Shopping	10%	15%
Home	37%	38%
Chauffeuring	6%	10%
Personal Business	3%	4%
Social/Recreation	17%	17%

Trends in activity and travel demand patterns that result from changes in society are highly significant for transportation planning since they will have a major effect on future traffic patterns in urban areas. In particular, trip making is becoming increasingly complex both in terms of the structure of individual trips - increased trip chaining - and the propensity to make multiple trips each day. However traditional planning models, such as the four-step model, compress activity patterns into a small number of trip purposes then treat each of these purposes separately. The traditional models do not incorporate explicit links between these trip purposes nor a mechanism for representing interactions between activities, the underlying trip making process, or the effects of long term trends in the underlying activity pattern. It follows that traditional techniques, especially the four-step model, do not capture some of the key aspects of personal travel behaviour and are not adequately reflecting changes in trip patterns. Indeed, it could be argued that the first step of a four-step model has already assumed away the processes underlying many of the major trends and policy issues facing transport planning.

Despite the well known short coming of the four-step model - see Mannheim (1979) for a critique - and considerable progress on alternative paradigms, the four-step model is still the most commonly used approach and is institutionalised in thousands of applications throughout the world. This situation is likely to continue for the short to medium term. In the longer term, future transport planning models are likely to adopt an activity-based and point-to-point approach instead of the traditional trip-based, zone-to-zone approach. Activity-based point-to-point modeling is a key research strand of the Transport Model Improvement Program currently underway in US but it is likely to be many years before this approach is engendered in common practice. For a progress report on research towards the development of a new generation of travel demand models, see Spear (1996).

In the short term, there is an opportunity to improve the way that the four-step model, sketch planning and related models represent travel behaviour. This paper is concerned with the development of a technique for representing the link between trip purposes at the aggregate level and the underlying activity processes. Using this technique, it will then be possible to incorporate the effect of some of the current trends in society and resulting travel behaviour into the traditional transport modelling paradigm.

The paper proposes a model based on using Markov chains and a larger number of more specific trip purposes to represent large-scale patterns in urban travel behaviour. Therefore the model is at the macroscopic level and could be considered to be suitable for sketch planning and as an input to more detailed analysis. The use of Markov chains to represent urban travel behaviour is not new but previous applications have focused on representing and simulating the activity sequences of individual travellers (Sasaki, 1972; Kondo, 1974; Lerman, 1979; Damm, 1982; Damm and Lerman, 1981; Kitamura and Lam, 1983), or provide an alternative approach to the stochastic traffic assignment problem in which each node of the network is associated with a state of the Markov process (Sasaki, 1965; Akamatsu, 1996). It should also be recognised that the fundamental property of a Markov process - that the current state of the system depend only on its previous state - is also the underlying assumption in most stochastic assignment algorithms, notably Dial's algorithm (Dial, 1971).

The significance of this paper is that it develops a simple and practical technique for extending the traditional transport planning paradigm to include the effect of underlying social trends and their impact on the pattern of demand for travel. In this way, a greater number of relevant policy variables can be incorporated into the modelling process.

2. ACTIVITIES AND TRIP MAKING

Before discussing model development, it is worthwhile considering the characteristics of the underlying activity and trip making processes. The discussion also introduces terminology and several important properties that will be used in the development of the model. For the purposes of this paper, the term *trip* will be used to describe a tour that may involve several activities and *trip segment* will be used for travel between a particular pair of activities.

It is axiomatic that individuals make trips for a purpose and that the purpose is to undertake particular activities. It follows that activities drive the trip making process, and that activities would form a better basis for urban transport modelling than trips. Considerable research has been devoted to examining and modelling the activity patterns of individuals and the resulting transport demand (Damm, 1980, 1982; Kitamura, 1983; Nishii et al, 1988; Stopher et al, 1996). According to Stopher et al (1996), activities can be classified into three categories

- *mandatory activities* have frequency (typically daily), location and timing that are all fixed. The best examples are work and school.

- *flexible activities* are performed on a regular basis but some of the characteristics (such as timing or location) may vary. Examples include grocery shopping and banking.

- *optional activities* are discretionary and all characteristics may vary. In particular, frequency may be zero in a given time period. Examples include social and recreational activities.

Typically these activities will generate a primary trip each day, which in most cases will be the journey to work but may be the journey to school or other mandatory activity. As the name suggests, most persons will have one primary trip per day. Each traveller may also have one or more secondary trips which are flexible and/or discretionary with a wide range of possible trip purposes.

Each trip may involve a single activity or several activities may be linked together to form a trip chain. If the fundamental planning unit is the trip chain instead of individual trip segments then the traveller's home can be considered to be the origin and destination of all urban trips. In other words, all trips can be considered to be home-based trips, irrespective of how many intermediate destinations are visited. Of course this is an over-simplification since some trips, such as tourist trips from hotels, are not home-based. However the number of non-home-based trips will be very small in the context of all urban trips. A recent survey undertaken in Melbourne (Fan and Bougatsis 1996) reported that over a 24 hour period more than 90% of daily trips are home-based chains. The actual proportion of home-based trips is even higher because trips for a substantial number of persons will overlap the 24 hour period.

The richness and complexity of trip making behaviour can be contrasted against the approach used to model urban travel using traditional modelling paradigms. The hierarchy of aggregation and simplification inherent in traditional approaches can be represented as follows:

- the desire or need to undertake activities generates a demand for trips. The pattern of activities is strongly influenced by society and socio-economic and demographic characteristics.
- trips are prioritised and organised according to social, time and locational constraints and may involve a single activity or chains of linked activities
- the full range of activities is grouped into a small set of categories, such as home, work, shopping, education, social visits, recreation, medical, and personal business.
- each trip segment is classified according to the activity undertaken at each end of the trip, such as a trip from home to work, or from work to shopping.
- the classified trips are summarised into a trip table which shows the number of trips between each pair of activity categories. In practice, this table is derived from a survey of travellers.
- the trip table is summarised into the number of trips in a set of six to eight trip purposes, such as home-based work trips, home-based shopping trips, non-home-based trips.
- the trip purposes are compressed into an even smaller number of standard trip types, typically home-based work, home-based other, and non-home-based.

Traditional transport planning models use the results of either the highest or second highest level of the hierarchy as input to the modelling process. In doing so, the link back to the original activities, social processes and trip chains that generated the aggregate trip numbers is broken. The aim of this paper is to develop a simple sketch planning model that re-establishes that link and allows the effects of social trends and processes to flow through to traditional transport planning models.

3. MARKOV PROCESSES AND ACTIVITY CHAINS

Consider the process of making trips in an urban area. Over the course of a day, individual travellers move from one activity to another in a series of trip chains. The sequence of activities is a personal decision but at the macroscopic level, there will be some degree of regularity so that transitions between certain combinations of activities are more likely than others. This situation is equivalent to transitions between states of a Markov process. It follows that trip chaining between activities can be modelled at the macroscopic level using Markov chains. As mentioned above, this use of Markov chains is somewhat different to previous applications because the model is at the macroscopic level and each state of the Markov process corresponds to a generic activity group. There is no reference to locations or individual travellers. It should also be recognised that the model is not time dependent so there is a sense of sequencing but no sense of duration attached to the activities.

There has been some debate about the validity of the Markov process in describing trip chaining behaviour since Markov processes engender the assumption that the current state of the system depends only on its previous state. In other words there is no memory or forward planning. Analysis of individual trip chains, see Damm (1980) and Kitamura (1983), has shown that trips are more organised and systematic than suggested by a Markov chain. Trips chains are dependent on activities already pursued that day with a tendency to less-flexible activities occurring first. There is also evidence, Hishii, Kondo and Kitamura (1988) that the propensity to chain trips increases with commuting distance, travel cost, and the density of activity opportunities. These criticisms are pertinent when Markov models are used to describe individual travel behaviour but are less serious for a macroscopic model of since the overall trip making behaviour of a large number of travellers is likely to appear less systematic than that of a particular individual.

Consider a Markov process in which each state corresponds to a generic activity, such as home, work, education, shopping, recreation, chauffeuring. Let there be n such generic activities (or states) where in general, n will be larger than the number of trip purposes used in traditional transport planning models. The set of system states includes 'home' separately as both trip origin and destination. The reasons for explicitly including both roles for 'home' are that it

- reflects the property that all trip chains can be considered to be home-based.
- explicitly identifies origin, destination and intermediate states.
- creates an absorbing state of the Markov process and offers significant theoretical advantages

The other key element of the Markov model of trip making behaviour is a transition matrix whose elements are the conditional probabilities of transitions between particular states of the system. Let **P** be an n x n matrix with the following properties

- Each row of **P** represents a different activity that can take place at the origin of a trip segment, such as home, work, shopping, other.
- Each column of **P** represents an activity that can take place at the destination of a trip segment. The set of generic activities is the same for rows and columns of the matrix.
- Each element P_{ij} is the conditional probability P(j|i) that a trip segment with activity j at its destination has activity i at its origin. Therefore

$$\Sigma_j P_{ij} = 1$$

The transition matrix **P** is similar to a traditional trip purpose table whose elements are the number of trips between each pair of activity categories. Indeed the conditional probabilities which are the elements of **P** can be derived from the trip table by normalising its rows. The key differences is that **P** includes home as both trip origin and destination. Table 2 shows an example of a transition matrix with a small number of generic activities.

Table 2 : Markov Transition Matrix

From \ To	Home (Origin)	Work	Shop	Other	Home (Destination)
Home (Origin)	0	0.60	0.20	0.20	0
Work	0	0.01	0.10	0.09	0.80
Shop	0	0.10	0.20	0.10	0.60
Other	0	0.10	0.20	0.10	0.60
Home (Destination)	0	0	0	0	1

The elements of the transition matrix in Table 2 are interpreted as follows; the probability that a trip segment starts ends at work given that it started from home and is 0.6, likewise the probability that the trip ends at shopping given that it started from works and is 0.1, and so on.

The transition matrix governs the evolution of a Markov process, or in this case the sequence of activities, or equivalently the structure of the trip chain. The state of the system is described by a vector $\underline{\mathbf{x}}$ whose elements correspond to the probability that the system is in each of the possible states. Since each state of the Markov process corresponds to an activity and each transition corresponds to a trip segment, the state vector evolves according to the sequence of activities undertaken by travellers and its elements are the probabilities for each activity at each step of the trip chain. Note that the sequence of activities is stochastic since each successive activity is selected with a probability that is governed by the transition matrix.

Since all trips are considered to be home-based, the initial state of the system described by the transition matrix in Table 2 can be written as

$$\underline{\mathbf{x}}^0 = (1,0,0,0,0)$$

Travellers then move from home to a new activity with probabilities for each subsequent activity given by the transition matrix. After the first transition, that is the first trip segment, the new state of the system is given by the standard Markov equation

$$\underline{\mathbf{x}}^1 = \underline{\mathbf{x}}^0 \, \mathbf{P}$$

After two trip segments, the state is

$$\underline{\mathbf{x}}^2 = \underline{\mathbf{x}}^1 \, \mathbf{P} = \underline{\mathbf{x}}^0 \, \mathbf{P}^2$$

and so on. Successive applications of the transition matrix evolves the traveller through a sequence of activities and constructs trip chains. Table 3 shows the sequence of states resulting from the transition matrix in Table 2.

Table 3 : Sequence of System States

	Home (Origin)	Work	Shop	Other	Home (Destination)
$\underline{\mathbf{x}}^0$	1	0	0	0	0
$\underline{\mathbf{x}}^1$	0	0.600	0.200	0.200	0.000
$\underline{\mathbf{x}}^2$	0	0.046	0.140	0.094	0.720
$\underline{\mathbf{x}}^3$	0	0.024	0.051	0.028	0.897
$\underline{\mathbf{x}}^4$	0	0.008	0.018	0.010	0.964
$\underline{\mathbf{x}}^5$	0	0.003	0.006	0.004	0.987
$\underline{\mathbf{x}}^6$	0	0.001	0.002	0.001	0.995
$\underline{\mathbf{x}}^7$	0	0	0.001	0	0.998
$\underline{\mathbf{x}}^8$	0	0	0	0	0.999
$\underline{\mathbf{x}}^9$	0	0	0	0	1
$\underline{\mathbf{x}}^{10}$	0	0	0	0	1

For example, after two trip segments, the probability that the traveller is at work is 4.6%, shopping is 14%, undertaking other non-home-based activities is 9.4%, and has returned home is 72%. Because Home (Destination) is an absorbing state of the Markov chain, all trips terminate there and the system will quickly converge to a state in which all travellers have returned home. Note that the value of the element of $\underline{\mathbf{x}}^k$ corresponding to Home (Destination) can be interpreted as the proportion of trips that have terminated after k legs. In this example, 72% of trips have terminated after 2 legs (out and back) which means that 28% are chained trips in which more than one non-home-based activity is undertaken before returning home. Likewise, more than 96% of trips have four or less segments (visit at most 3 intermediate destinations during the trip) and the number of trips with more than 9 segments is negligible. In terms of transport planning, one of the key features of this approach is that it incorporates trip chaining as an inherent feature.

The sequence of system states can be used to calculate the cumulative probability that the trips involved a trip segment between each possible combination of origin and destination activities. Let the matrix of cumulative probabilities be **T** then

$$T_{ij} = \Sigma_n x_j^n P_{ij}$$

Note that the values of elements of **T** will be different to the corresponding elements of **P** because **P** describes conditional probabilities for transitions between activities for a particular segment of a trip, while the probabilities in **T** relate to transitions between activity combinations occurring at any segment of a chained trip. Therefore **T** is equivalent to a traditional trip table which shows the number of trips between each pair of activity categories.

Table 4 shows the resulting matrix of cumulative transition probabilities for the example transition matrix in Table 2. The activities for Home as an origin and a destination have been merged to highlight the correspondence with a traditional trip table.

Table 4 : Matrix of Cumulative Transition Probabilities

To From	Home	Work	Shop	Other
Home	0	0.6	0.2	0.2
Work	0.55	0.01	0.07	0.06
Shop	0.25	0.04	0.08	0.04
Other	0.20	0.03	0.07	0.03

The same set of mathematical operations illustrated in the worked example can be represented more formally in terms of matrix algebra. Firstly, the transition matrix in Table 2 can be rearranged as follows

Table 5 : Activity Transition Matrix

To From	Home (Destination)	Home (Origin)	Work	Shop	Other
Home (Destination)	1	0	0	0	0
Home (Origin)	0	0	0.60	0.20	0.20
Work	0.80	0	0.01	0.01	0.09
Shop	0.60	0	0.10	0.20	0.10
Other	0.60	0	0.10	0.20	0.10

then the transition matrix represents an absorbing Markov process in the form investigated by Akamatsu (1996). Akamatsu was concerned with trip assignment in a traffic network and formulated the Markov process such that each state of the process corresponds to a node of the network. Therefore Akamatsu's interpretation of the transition matrix is quite different to that adopted in this paper. However the underlying mathematics of the process are the same and we can adopt Akamatsu's terminology and results. According to Akamatsu (1996), the transition matrix of the absorbing Markov process can be written in the form

$$\mathbf{P} = \begin{bmatrix} \mathbf{I} & \mathbf{0} \\ \mathbf{R} & \mathbf{Q} \end{bmatrix}$$

where **I** is a unit matrix, **0** is a zero matrix, **R** is the matrix of transitions direct to a destination, and **Q** is the matrix of transitions between states which are not destinations. Further, the matrix **Q** can be written as

$$\mathbf{Q} = \begin{bmatrix} \mathbf{0} & \mathbf{Q}_1 \\ \mathbf{0} & \mathbf{Q}_2 \end{bmatrix}$$

where $\mathbf{Q}_1$ is the matrix of transitions from origins and $\mathbf{Q}_2$ is transitions between intermediate states. Clearly, the transition matrix in Table 5 is in this form.

The type of Markov process considered in this paper has a single origin and a single destination. Therefore if the total number of states is n then the dimensions of the matrices are

$$\begin{aligned} \mathbf{R} &\equiv (n-1) \times 1 \\ \mathbf{Q} &\equiv (n-1) \times (n-1) \\ \mathbf{Q}_1 &\equiv 1 \times (n-1) \\ \mathbf{Q}_2 &\equiv (n-2) \times (n-2) \end{aligned}$$

According to the Markov chain rule, the probability that the system started in state i and is in state j after k transitions is given by the (i,j) element of $\mathbf{Q}^k$. The total probability that the system has passed through each state is

$$\begin{aligned} \mathbf{I} + \mathbf{Q}^1 + \mathbf{Q}^2 + \mathbf{Q}^3 + \ldots &= [\mathbf{I} - \mathbf{Q}]^{-1} \\ &= \begin{bmatrix} \mathbf{I} & \mathbf{Q}_1[\mathbf{I} - \mathbf{Q}_2]^{-1} \\ \mathbf{0} & [\mathbf{I} - \mathbf{Q}_2]^{-1} \end{bmatrix} \end{aligned}$$

This result can be used to calculate total numbers of trips for each transition type.

4. APPLICATIONS AND EXTENSIONS TO THE MODEL

The aim of this paper is to develop a simple sketch planning process that provides a link between traditional transport models and the social processes and trends that are influencing trip making behaviour at the macroscopic level. The Markov model provides a basis for establishing such a link since the transition probabilities reflect social processes and the model output can be converted to a trip purpose table suitable for use in a traditional modelling framework. Simply multiplying the cumulative transition probability matrix by the total number of trip chains returns a trip purpose table in traditional form. Therefore the Markov model developed in this paper fits into the modelling process before the first step of the traditional model and provide a link back to some of the fundamental behavioural and trip making processes.

The individual probabilities in the Markov transition matrix can be interpreted in terms of underlying social processes and hence become policy variables that can be used to implement observed social trends or investigate the effects of hypothetical trends. For example, by adjusting the relevant transition probabilities it is possible to explicitly include and control such trip making behaviours as

- the growing trend to drive children to school before work; implemented by adjusting the home to school and school to work transition probabilities,
- trip chaining after work; implemented by adjusting the probabilities of transitions from work to recreation, shopping, social and other non-home activities, and
- differences in pre- and post-work trip patterns; implemented by adjusting the to work and from work transition probabilities.

Further, the probabilities associated with home as a destination control the overall propensity to chain trips so it is easy to control the extent of trip chaining within the Markov model context.

The modelling framework can be readily extended in several ways to encompass a range of additional policy variables. The discussion so far has concentrated on the primary trip undertaken during a typical day. Let **S** be the transition matrix for subsidiary trips. In general, **S** will be very different to **P**, the matrix for the primary trip. In particular, the transition probabilities for mandatory activities will be lower and probabilities for flexible and optional activities will be higher. Let V_0 denote the percentage of primary trips in the day and V_i represent the percentage of the ith subsidiary trips undertaken. The values V_i can be expected to decline rapidly since the proportion of persons making a large number of separate home-based trips is likely to be small. Recall that all trips are considered to be home-based since the Markov chain takes care of trip chaining. It follows that the set $\{V_i\}$ can be used as an additional policy variable representing the relative number of trips undertaken each day. The transition matrix for all trips during the day can be constructed as follows

$$V_0 \mathbf{P} + \{\Sigma_i V_i\} \mathbf{S}$$

The adjusted transition matrix now includes a wealth of policy variables describing the pattern and structure of trip making behaviour and as shown above can be converted to a form appropriate for use in traditional transport planning models.

Some other straightforward extensions include

- segmenting the population of travellers into groups with similar trip making characteristics. For example, it is evident from Table 1 that male and female travellers have sufficiently different travel habits to warrant developing separate transition matrices. Creating transition matrices for each market segment introduces a new dimension into the set of policy variables and provides an opportunity to investigate a richer set of social and demographic trends using the Markov model.

- allowing a non-zero Home (Origin) to Home (Destination) transition probability corresponds to including all persons in the model and allowing for persons who do not make any trips during the day. This introduces an additional policy variable, corresponding to the daily travel participation rate.

So far, the discussion has concentrated on private trip making for individuals. However the Markov approach can also be adapted to modelling trip making by commercial vehicles in urban areas. For example, interpreting home as the depot and setting a relatively high probability to work-work transitions would create long trip chains that reflect the behaviour of delivery vans.

5. CONCLUSION

Traditional transport planning models, such as the four-step model, fail to reflect the increasing complexity of trip making behaviour and the influence of underlying social processes and trends. These models do not include a mechanism for representing interactions between activities, the underlying trip making process, or the effects of long term trends in the underlying activity pattern. Despite these and other well known short coming of traditional transport planning models and considerable progress on alternative paradigms, the four-step and related models are still the most commonly used approach and are institutionalised in thousands of applications throughout the world. This situation is likely to continue for the short to medium term.

The approach described in this paper provides a technique for incorporating some of the major current social issues and trends in urban travel patterns into the transport planning framework. The proposed model uses a larger number of more specific activity categories than is typically used and includes 'home' as both the origin of all chained-trips and as an absorbing state of the Markov process. Each generic activity corresponds to a state of the Markov process which means that the conditional probabilities of transitions between individual states can be interpreted as policy variables representing the propensity to link activities. For example, lowering the probability of the transition from 'work' to 'home' corresponds to the observed trend that travellers are less likely to come directly home from work but may detour to do some shopping or engage in a leisure activity. The model can also be extended to include multiple chained trips, market segmentation, and multiple transition matrices. The complete model includes a large number of parameters which can be interpreted as policy variables and used to represent the trends in society and travel behaviour.

The proposed Markov model represents trip making at a macroscopic level and can be used as a sketch planning model in its own right, or to provide input to a traditional transport planning model. As a sketch planning tool, the Markov model provides a mechanism for investigating the macroscopic effects on transport activity of postulated changes in society and trip making behaviour. For example, the effects of increased use of private motor vehicles by women, unemployed, or retired persons. It has also been demonstrated that the outputs from the Markov model can be adapted for use an input to a traditional transport planning model. Multiplying the cumulative transition matrix by the expected number of trip chains produces a trip purpose table comprising the number of trips between each pair of activity categories. This trip purpose information is a key input to the trip generation phase of a four-step model. Therefore the Markov model proposed in this paper can occupy a position in the traditional planning process before the 'first step' and allow a greater number of relevant policy variables can be incorporated into the modelling process. In so doing, the Markov model provides a simple and practical technique for extending the traditional transport planning paradigm to include the effect of underlying social trends and their impact on the pattern of demand for travel.

REFERENCES

Akamatsu T. (1996) Cyclic flows, Markov process and stochastic traffic assignment. ***Transpn Res*** **30B**, 369-386.

Damm D. (1980) Interdependencies in activity behaviour. ***Transportation Research Record*** **750**, 33-40.

Damm, D. and Lerman, S. (1981) A theory of activity scheduling behaviour. ***Environment and Planning A13***, 1377-1388.

Damm D. (1982) Parameters of activity behaviour for use in travel behaviour. ***Transpn Res*** 16A, 135-148.

Fan, M and Bougatsis, J (1996) Transport challenges for the new leisure class. **Proc. 20th Australasian Transport Research Forum**, Auckland.

Kitamura R. (1983) Sequential, history-dependent approach to trip-chaining behaviour. ***Transportation Research Record*** **944**, 13-22.

Kitamura R. and Lam T.N. (1983) A time dependent Markov renewal model of trip chaining. In ***Proceedings of the Eighth International Symposium on Transportation and Traffic Theory*** (Edites by V.F. Hurdle, E. Hauer and G.N. Steuart, 376-402). Toronto University Press, Toronto.

Kondo K. (1974) Estimation of person trip patterns and modal split. **In *Transportation and Traffic Theory*** (Edited by D. Buckley, 715-742). Elsevier, New York.

Morris, J,M., and Richardson, A.J. (1996) The emerging needs of the majority - women, young and old. **Proc. 20th Australasian Transport Research Forum**, Auckland.

Lerman S. R. (1979) The use of disaggregate choice models in semi-Markov process models of trip chaining behaviour. ***Trans Sci*** **13**, 273-291.

Nishii K., Kondo K. and Kitamura R. (1988) Empirical analysis of trip chaining behaviour. ***Transportation Research Record*** **1203**, 48-59.

Richardson, A.J., Morris, J.M. and Loeis, M (1996) Changing employment and income profiles - a new environment for travel demand. **Proc. 20th Australasian Transport Research Forum**, Auckland.

Sasaki T. (1965) Theory of traffic assignment through Absorbing Markov Process (in Japanese). ***Proc JSCE*** **121**, 28-32.

Sasaki T. (1972) Estimation of person trip patterns through Markov chains. **In *Traffic Flow and Transportation*** (Edited by G.F. Newell, 119-130). Elsevier, New York.

Spear B.D. (1996) New approaches to transportation forecasting models. ***Transportation*** **23(3)**, 215-240.

Stopher P.R., Hartgen D.T. and Yuanjun Li (1996) SMART: simulation model for activities, resources and travel. ***Transportation*** **23(3)**, 293-312.