The Development of Trip Chaining Approaches in Travel Demand Modelling

by

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Abstract

The purpose of this paper is to incorporate trip chaining into travel demand analysis, and also to develop a model for an estimation of trip generation. Before the discussion on the model formulation, a brief historical review of trip chaining approaches is presented, and some validations of those approaches are explored.

The model proposed here is able to explain the derived nature of travel demand due to various kinds of business activities in a metropolitan area. One particular concern is to describe the cycle-sojourn zone distribution, which plays an important role for generating a sequence of business trips. In this model, the cycle-sojourn zone distribution is formulated by applying an entropy maximizing distribution model of the gravity type. From its application, it can be found that this model is useful for representing business trip chaining behaviours in a single day.

1. Introduction

This paper describes the development of models incorporating trip chaining into travel demand analysis. It is emphasized that these analyses have to represent the daily travel behaviour, which forms the trip chaining derived from a person's various activities in that day. This paper is divided into four sections.

The first section reviews previous trip chaining researches, and also shows their analytical framework by considering the main subjects for discussion in this field. Here, markovian approaches are regarded as typical ones, while activity-oriented approaches and disaggregate utility-modelling approaches are referred to as related ones. The second section discusses some validations of a trip chaining approach. There are five aspects, as follows: (1) trip linkages, (2) modal choice decision-making in a trip chain, (3) the derived nature of travel demand, (4) the travel patterns in a single day, and (5) time budget constraints. Some of these aspects have an important role in the model formulation in the following section.

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In the third section, an estimation model of trip generation is formulated. Of a particular concern is the improvement of the trip-generation model. (See Sasaki & Nishii (1983).[1]).. The fourth section discusses an application to business trip chaining behaviours in a metropolitan area. The model specification is put into practice, based on an empirical analysis of travel patterns in business trip chains. The results suggest that this approach can be in a position to represent the business travel behaviours derived from industrial and commercial activities in that area.

2. Background

2-1. Previous Researches

A Markovian approach has been ridden in advance of trip chaining researches since Overgaard (1963) introduced the concept of linked trips or chains of trips. In the 1960's, simple Markov chain models were developed to describe the characteristics of trip chaining such as the trip linkages and the spatial interactions between the facilities of trip-ends. [Marble (1964)[2], Horton & Schuldiner (1967)[3], and Horton & Wagner (1969)[4].] It was in the 70's that many researchers discussed an application of those models to travel demand forecasting. Sasaki (1971)[5] proposed an absorbing Markov chain model for estimating trip distribution. Gilbert (1972)[6] developed a Markov renewal model to describe the structure of linked trips. The model, in which the times of transition between states are assumed to form a probabilistic process, yields the number of times that a destination is visited, and the amount of time spent at a destination as well as the number of destinations visited. The extensions of Markovian trip chaining models to modal split were also investigated. [Richard & Wigan (1973)[7], Kondo (1974)[8]] In particular, Kondo (1977) discussed the problem about how to estimate the probability of transition between states in the future stage of a travel demand forecasting procedure. In the 80's, Kitamura & Lam (1981)[9] proposed a theoretical model by modifying a Markov renewal process of trip chaining. The model has the advantage of incorporating a time dependent transition probability and the sojourn time disitribution. It may allow a more elaborate representation of trip chaining behaviours, but it remains to investigate its capability in a practical application. Therefore, one of the promising directions for future Markovian researches is expected to improve the model-structure in order to raise its applicability in travel demand analysis.

An activity-based approach has raised its head in travel demand modelling since an analytical framework was proposed in the 70's. [Hagerstrand (1970)[10], Hemmense (1970)[11].] The researches of T. S. U. of Oxford University have had a principal role in this field. Particularly, the workshop, held by this group in 1975, indicated that terminologies in trip chaining research were used in an incomplete manner, and also the empirical results of previous studies were compared with each other. [Jones (1975)[12], Hensher (1976)[13], and Heggie (1976)[14].] Dix (1977)[15] and Jones (1977)[16], later developed the gaming simulation model named HATS, which represented the travel behaviours derived from daily activities in a household unit. Recent advances in this approach have been extended to the comprehensive ranges of travel demand analysis. Some of main subjects for discussion may be classified into three categories as follows: The first concerns interdependencies between household members in daily activities and deals with an effect of the life cycle stage on the choice-problem in activity pattern. [Damm (1980a)[17], Hanson & Hanson (1981)[18], Burnett & Hanson (1982)[19], and Kitamura & Kostyniuk (1982)[20].] The second subject is to analyze the temporal and spatial interactions between daily activities, and to develop a model of time-space path taking the time budget constraints into consideration. [Wigan & Morris (1981)[21], Supernak & Zahavi (1982)[22], and Kitamura (1984)[23].] The third category is concerned with an extension of those activity-based models to the evaluation problems related to transport policy decision-making. [Carpenter & Jones (1983)[24], Damm (1980b)[25].]

There have not been many trip chaining studies categorized into the utility approach. Adler & Ben-Akiva (1979)[26] developed a utility-maximizing model of non-work trip chaining behaviour. This contains the means of decision making for the determinants of both the number of tours and the number of sojourns in a trip chain. The utility of a travel pattern is expressed as a function of such factors as scheduling convienience, travel expenditures, attributes of the set of destinations and individual characteristics. Also, it is constrained as to the amount of money and time which a trip-maker can spend on travel in a given day. This model may be suggested for modelling a trip chaining behaviour, but it will be necessary to convert the time budget constraint into a practical manner in order to consider its important role for determining travel patterns explicitly. The random utility approaches, in which a multi-nominal logit model is one of the most typical, have been applied to the choice problem in a trip chaining behaviour. Lerman (1979)[27] discussed the logit type model for destination and modal choice in the Markov renewal process of trip chaining. Horowitze (1980)[28] proposed a utility maximizing model of the tour formation in a chain of multi-destinations. Kitamura (1984)[29] incorporated trip chaining into multi-destination choice modelling. In particular, it can be pointed out that the future dependency of each sojourn in a trip chain influences the expected utility which determines a destination choice behaviour. Those disaggregate choice modellings may be distinguished for the theoretical framework which is called a random utility theory. It, however, remains to solve the aggregation problem in their application to practical travel demand forecasting.

2-2. This research

The framework of this research is divided into the following two parts: One is an analysis of travel patterns in trip chaining behaviours, and the other concerns trip chaining modellings for an estimation of trip generation, trip distribution, and modal split. The former deals with factors determining travel patterns in trip chaining behaviours. Trip chain data have been investigated through classifications of their travel patterns by taking trip-makers' individual attributes into consideration. [Nishii (1978) (30)] Here, the travel patterns are defined by both the number of cycles and the number of sojourns in a trip chain. For example, it can be found that trip chains are classified by typical travel patterns such as the piston-type (one sojourn), the two sojourn-type (1 cycle 3 trips, 2 cycles 4 trips), and the round-type (between 3 sojourns and 8 sojourns). Also, in the case of business trip chain data, travel patterns are characterized both by the business conduct in which a trip-maker engages, and by the spatial interactions between his base-zone and the sojourn-zones he visits in that day. On the other hand, this paper is put into the latter position, and concerns the development of a trip chaining model for travel demand forecasting. An estimation model of trip generation for business trip chaining has been previously proposed. [See Sasaki & Nishii (1983).] The purpose of this paper is to improve the model so that it may represent trip chaining more explicitly. Especially, the relations between a cycle formation and sojourn zone distribution are incorporated into the model formulation.

3. Validations of trip chaining approaches

Some useful aspects for travel demand analysis have been pointed out through previous researches on trip chaining behaviours. Here, we try to arrange the following five aspects as regards to validations of trip chaining approaches: (31)

The first of these approaches, "trip linkage" , has been often discussed in order to represent travel behaviours in a day. It happens that as a person's travel behaviour in a single day is composed of the sequence of trips having different trip purposes, each successive trip is influenced by the preceding trip. However, the trip-unit method, in which each trip is assumed to be independent, can not explain the relations between such trips. For examle, when a commuter's piston-type travel pattern having one work-trip and one return-trip is forced to be modified to the triangle-type in which a shopping-trip is added, it should be necessary for the explanation of such a modification to take trip linkage into consideration.

Secondly, "a modal choice decision making for each trip in a trip chain" should be also explored as the decision making in a trip chaining process. Particularly, when a trip-maker has to decide whether he will choose a car or not, he may consider his whole travel behaviour for that day, because it is very difficult for a car-user to change the mode in trip chaining. It has been obtained from the analysis of business trip chainings that the probability of choosing a car in the first trip tends to become larger with an increase of the number of sojourns in the business trip chain. This suggests that it is useful for the representation of modal choice decision-making to focus attention on the travel pattern in a trip chain.

The third aspect concerns "the derived nature of travel demand" . In an urban area, various economic activities result in a travel demand which forms a business trip chain, including a certain number of sojourns which a trip maker has to make in a day. Therefore, each stage of the demand forecasting process, such as trip generation, OD distribution, and modal split should not be explained independently, but expressed as a systematic process of trip chaining. While business trip chains are generated by the need of commercial dealings between a trip maker and his customers, it can be found from the examination of those data that, in the business trip chain starting with a business-trip, the change in a trip-purpose from business to another is hardly seen. Also, the number of sojourns in a business trip chain is determined by the characteristics of his industry. In the following section, we will discuss the improvement of a business trip generation model by incorporating a decision making for both the number of cycles and the distribution of sojourn-zones into an estimation procedure of trip generation.

The fourth aspect is concerned with "travel patterns in a single day" . We here suppose that completeness of a travel pattern has an important role on the decision-making of a trip chaining in a day. Through classification of daily travel patterns for trip chaining data, the effect of trip-makers' attributes on their travel patterns have been investigated. Furthermore, the temporal and spatial stability of travel patterns has been examined. These analyses are expected to be useful for clarifying the characteristics of trip production from the viewpoint of trip chaining. Also, they are regarded as being basic empirical investigations for modellings of travel demand forecasting.

The fifth aspect is concerned with "time budget constraints" in the formation of trip chaining. This aspect can be important in the case where the analytical framework of travel patterns is extended to the temporal and spatial dimensions. The activity-oriented approach is promising for representing daily travel behaviours under these constraints. The following subjects may remain in this field: the trade-off between travel time and activity time, the time-scheduling under a certain travel pattern, and the activity-program related to the combination of an obligatory activity and a discretionary one. It is necessary to analyze the temporal characteristics of an activity pattern in trip chaining through an empirical data collection.

4. A trip chaining model for an estimation of trip generation

4-1 The basic concept

The purpose of this modelling is to represent a business trip chaining in the travel demand forecasting procedure explicitly, by improving the model developed previously.

A business trip chain is defined as a sequence of the trips, which are derived from commercial activities in an urban area, such as negotiations, deliveries of goods, and laying in stock. From the empirical analyses of business trip chaining data, the features are summarized as follows: 1) Some typical travel patterns can be found out from the classification of both the number of sojourns and the number of cycles. 2) The probability of having a certain number of sojourns tends to decrease along the exponential curve with an increase of the number of sojourns in a trip chain. This tendency is characterized by reflecting on the business conduct in which the trip-maker is engaged. 3) As the number of trips in a trip chain is equal to the total amount of both the sojourns and cycles, a trip generation can be estimated by summing up the number of the sojourns distributed into each zone and the number of cycles generated at the base zone.

By paying attention to those features in business trip chaining, a trip generation model has been proposed in the previous study [Sasaki & Nishii (1983)]. The model had a special capability to explain the nature derived from business activities. In the model, particularly, the interaction between a trip maker's base and his sojourns is regarded as one of the most dominant factors for characterizing the distributions of sojourn zones, and is explored with the relative accessibility. However, it remains to be solved that the effect of the cycle formation on distributions of sojourn zones has to be incorporated into a trip chaining process. The basic idea concerning this problem will be mentioned below.

Let us suppose the cycle-sojourn zone distribution as in Table-1, where the row means the number of cycles in a trip chain, and the column corresponds to the sojourn- zone distributed. When the business trip chain having a certain number of sojourns is generated from the base zone, each of the sojourns is distributed into the cell of this matrix by both the number of sojourns and the kind of base zones. Therefore, the value of the cell ($f_{\ell j}^{(s,i)}$) means the total amount visiting the j-th zone as a sojourn from the i-th base zone with the travel pattern [tp(s, ℓ)], where the suffix S is the number of sojourns and the suffix ℓ is the number of cycles. The variables

Sojourn zone No. of cycles	1	2	··········	j	··········	N	
1	f_{11}	f_{12},	..........,	f_{1j},	..........,	f_{1N}	ϕ_1
2	f_{21}	f_{22},	..........,	f_{2j},	..........,	f_{2N}	ϕ_2
⋮	⋮	⋮		⋮		⋮	⋮
ℓ	$f_{\ell 1}$	$f_{\ell 2}$,	..........,	$f_{\ell j}$,	..........,	$f_{\ell N}$	ϕ_ℓ
⋮	⋮	⋮		⋮		⋮	⋮
S	f_{s1}	f_{s2},	..........,	f_{sj},	..........,	f_{sN}	ϕ_s
	ψ_1	ψ_2 ,	..........,	ψ_j ,	..........,	ψ_N	T

Table 1. The cycle–sojourn zone distribution for trip chains having S sojourns from the i–th base zone

shown in Table-1 are defined as follows:

$$\Phi_\ell^{(s,i)} = \sum_{j=1}^{N} f_{\ell j}^{(s,i)}, \tag{1}$$

$$\Psi_j^{(s,i)} = \sum_{\ell=1}^{S} f_{\ell j}^{(s,i)}, \tag{2}$$

$$T^{(s,i)} = \sum_{\ell=1}^{S} \sum_{j=1}^{N} f_{\ell j}^{(s,i)}, \tag{3}$$

where $\Phi_\ell^{(s,i)}$ is the total number of sojourns generated by the trip chains starting from the base zone i with tp (s, ℓ), $\Psi_j^{(s,i)}$ is the total amount of the sojourns distributed to the sojourn zone j, and $T^{(s,i)}$ is equal to the total number of the sojourns generated by the trip chains having S sojourns from the i-th zone.

Here, if the matrix as in Table-1 is estimated in the future stage, the trip generation U_k can be obtained by both the estimated value of $\Psi_k^{(s,i)}$ and the estimated number of cycles (Λ_k) as shown in the following equation:

$$U_k = \Psi_k + \Lambda_k, \tag{4}$$

where,

$$\Psi_k = \sum_s \sum_i^N \Psi_k^{*(s,i)} = \sum_s \sum_i^N \sum_{\ell=1}^S x_{\ell j}^{(s,i)}, \tag{5}$$

$x_{\ell j}^{(s,i)}$ is the estimated value of $f_{\ell j}^{(s,i)}$.
Also, Λ_k can be expressed as follows:

$$\Lambda_k = \sum_s \sum_{\ell=1}^S [TC_k\ (s) \bullet {}^{k*}\omega_\ell \bullet \ell], \tag{6}$$

where, TC_k (s) is the number of trip chains with S sojourns from the k-th zone, and ${}^{k*}\omega_\ell$ means the relative weight of generating the ℓ cycles type of trip chaining in the k-th base zone in the future stage.

4-2. The model formulation

In this paper, the entropy-maximizing distribution model of the gravity type is adopted for estimating the cycle-sojourn zone distribution mentioned in the previous paragraph. This model is divided into the following four steps, as shown in Fig.1.
(1st step) Here, the form of an "a priori" probability of the cycle-sojourn zone distribution is assumed to be the gravity type written as follows:

$$P_{\ell j}^i = \alpha_0^i \lambda_\ell^i \mu_j^i \rho_{\ell j}^i, \tag{7}$$

for the trip chain having S sojourns from the i-th zone, where $P_{\ell j}^i$ is an "a priori" probability of the (ℓ, j) cell of the cycle-sojourn zone distribution, λ_ℓ^i is the relative power producing ℓ cycles, μ_j^i is the relative power attracting the j-th sojourn zone, $\rho_{\ell j}^i$ is the factor representing the interaction between the cycle pattern and each of sojourn zones, and α_0^i is a constant which ensures

$$\sum_\ell \sum_j P_{\ell j}^i = 1.$$

Here, in order to calibrate such an "a priori" probability, each of those components in Eq. (7) is formulated in a concrete manner. The "a priori" probability in the base year is defined as follws:

$$P_{\ell j}^i = f_{\ell j}^i / T^i, \tag{8}$$

where, as the suffix S is ommited to avoid the complexity of the expression,

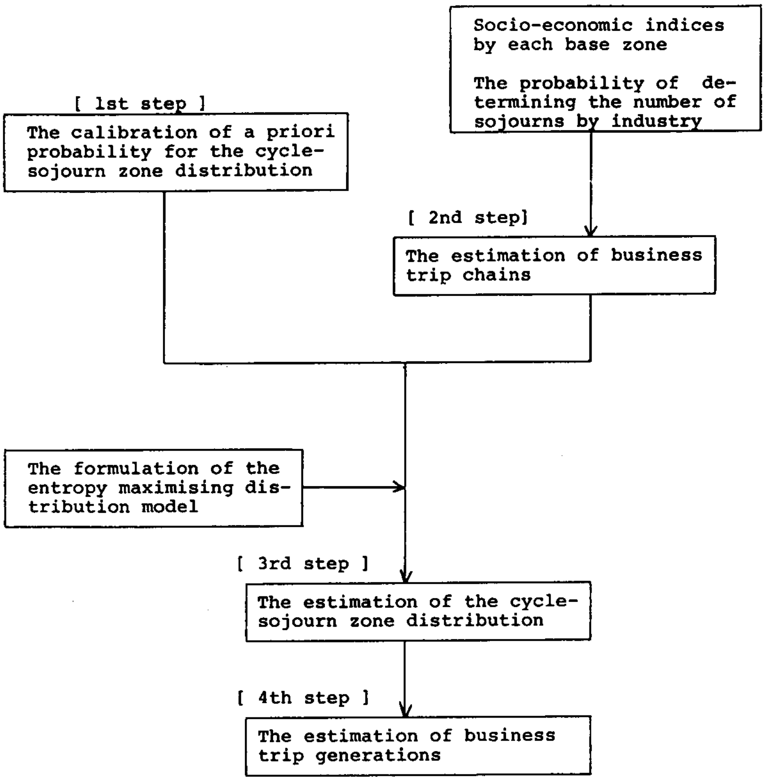


Figure 1. The flow chart of a trip generation model

$f^i_{\ell j} = f^{(s,i)}_{\ell j}$, $T^i = T^{(s,i)}$ as in Table-1.

The producing power is assumed to be the relative weight of forming ℓ cycles travel pattern, and to be written as

$$\lambda^i_\ell = ({}^i\omega_\ell)^\beta, \tag{9}$$

where β is a parameter, and

$$ {}^i\omega_\ell = \sum_j f^i_{\ell j} / T^i. \tag{10}$$

On the other hand, the attracting power is assumed to be expressed as a function of the relative accessibility between the i-th base zone and the j-th sojourn zone written as

$$\mu^{i}_{j} = ({}_{i}A_{j})^{\theta}, \tag{11}$$

where,

$${}_{i}A_{j} = \frac{E_j / t_{ij}}{\sum_{k} (E_k / t_{ik})}, \tag{12}$$

${}_{i}A_{j}$ is a relative accessibility, E_k is the number of persons engaged in the k-th zone, t_{ik} is the travel time between zones.

The interaction factor is assumed to be expressed as

$$\rho^{i}_{\ell j} = t_{ij}^{-\gamma_\ell}, \tag{13}$$

where t_{ij} is the travel time between the base zone i and the sojourn zone j, and γ_ℓ is a distance parameter for the ℓ cycles pattern.

Therefore, the parameters in Eqs. (9), (11), and (13) are estimated by rewriting Eq. (7) to

$$P^{\ell}_{ij} = \alpha_{\ell} \, ({}^{i}\omega_{\ell})^{\beta\ell} \, ({}_{i}A_{j})^{\theta\ell} \, t_{ij}^{-\gamma_\ell}, \tag{14}$$

where α_ℓ, β_ℓ, θ_ℓ, γ_ℓ, ($\ell = 1, \ldots\ldots, s$) are parameters.

(2nd step) The number of business trip chains generated from each base zone by industry is estimated by using the linear regression equation in which explanatory variables are socio-economic indices, such as persons engaged, establishments, and the floor area. As one of the simplest cases, the equation is written as follows:

$$N^{m}_{i} = a^{m} + b^{m} I^{m}_{i}, \tag{15}$$

where N^{m}_{i} is the number of business trip chains from the i-th zone for the m-th industry, I^{m}_{i} is a socio-economic index in the i-th zone by industry, and a^{m}, b^{m}, ($m = 1, \ldots, M$) are parameters by industry.

Furthermore, in this step, it is necessary to estimate the number of the business trip chains having S sojourns respectively. Then, the probability of determining the number of sojourns, which has been found to be expressed as the exponential curve, is written as follows:

$$TC_i(s) = \sum_{m}^{M} TC^{m}_{i}(s) = \sum_{m}^{M} [N^{m}_{i} Pr^{m}(s)], \tag{16}$$

where $TC_i(s)$ is the total number of business trip chains having S sojourns from the i-th zone, and

$$Pr^{m}(s) = \kappa_m (\nu_m)^{s}, \tag{17}$$

which is the probability of determining the number of sojourns for the m-th industry, and κ_m, ν_m are parameters.

(3rd step) In this step, the cycle-sojourn zone distribution is estimated by using the technique of the existing entropy maximizing distribution model.

Now, we consider a joint probability that each sojourn in the trip chain having S sojourns from the i-th zone is distributed to the (ℓ, j) cell of the joint probability, and is written as

$$P = \frac{z^{i}!}{\prod\limits_{\ell j} x^{i}_{\ell j}!} \prod_{\ell j} (\overset{*}{P}{}^{i}_{\ell j})^{x^{i}_{\ell j}}, \tag{18}$$

where, $x^{i}_{\ell j} = x^{(s,i)}_{\ell j}$, is defined as the estimated value of $f^{(s,i)}_{\ell j}$, $\overset{*}{P}{}^{i}_{\ell j}$ is the estimated value of $P^{i}_{\ell j}$ written as

$$\overset{*}{P}{}^{i}_{\ell j} = \alpha^{i}_{0} ({}^{i}\overset{*}{\omega}_{\ell})^{\beta_\ell} ({}_{i}\overset{*}{A}_{j})^{\theta_\ell} \overset{*}{t}{}^{-\gamma_\ell}_{ij}, \text{ and} \tag{19}$$

$Z^{i} = \sum\limits_{\ell} \sum\limits_{j} x^{i}_{\ell j}$ is equal to $TC_i(s)$ in Eq. (16).

Then, our problem is expressed as follows: Maximize P, subject to

$$\sum_{j} x^{i}_{\ell j} = Y^{i}_{\ell} \tag{20}$$

where Y^{i}_{ℓ} is the estimated number of sojourns of the trip chains with tp (s, ℓ) from the i-th zone, written as

$$Y^{i}_{\ell} = \sum_{m} TC^{m}_{i}(s)\, {}^{i}\overset{*}{\omega}{}^{m}_{\ell}. \tag{21}$$

This problem can be solved by usuing Lagrangian multipliers. The solution is written as follows:

$$x^{i}_{\ell j} = z^{i} \bullet {}^{i}\overset{*}{\omega}_{\ell} \bullet \frac{({}_{i}\overset{*}{A}_{j})^{\theta_\ell} \overset{*}{t}_{ij}{}^{-\gamma_\ell}}{\sum\limits_{k} ({}_{i}\overset{*}{A}_{k})^{\theta_\ell} \overset{*}{t}_{ik}{}^{-\gamma_\ell}}. \tag{22}$$

(4th step) As the final step of the estimaton process, a business trip generation can be calculated by using Eqs. (4), (5), and (6) mentioned in the previous paragraph. Here, the number of sojourns distributed to the j-th sojourn zone by the trip chains having S sojourns and ℓ cycles from the i-th base zone is given by Eq. (22) in the 3rd step. The number of trip chains having S sojourns from the i-th base zone is obtained from Eq. (16) in the 2nd step. The value of ${}^{i}\overset{*}{\omega}_{t}$ in Eq. (6) is assumed to be the same as the observed one.

5. An application

In this section, the proposed model is applied to a practical example of the Osaka metropolitan area. As shown in Figure 2, Osaka city is divided into eight zones as the internal area, and the total number of zones is 25 zones. The data used in this model were selected from the person-trip survey in 1980, which recorded the entire information of trips in a day by persons engaged in Osaka city.

Here, each step of this estimation process is discussed in order. In the first step, the "a priori" probability was calibrated by the log-linear regression methed. Table-2 shows the estimated parameters in Eq. (14) for each travel pattern tp (s, ℓ), and Table-3 represents the coefficient of correlation by the number of sojourns. These tables lead to the following:

1) It can be found from Table-3 that, the results in the case where the number of sojourns is less than five are satisfactory, though the fitness in cases of more than six sojourns tends to decline with an increase of the number of sojourns. This seems to be caused by the number of samples having a tendency to decrease extremely in cases of more than the six sojourns-travel patterns.

2) The estimated values of the distance parameter in Table-2 are illustrated in Figure-3. We can find that they tend to decrease with an increase of the number of sojourns under a certain number of cycles, and also to increase with the number of cycles. This implies that, in the case of the one cycle round-type having multi-sojourns, the distance friction between the base zone and the sojourn zone is reduced with an increase of the number of sojourns, and that it becomes more sensitive in the case of the travel pattern visiting each multi-sojourn directly.

3) The estimated values of the relative accessibility parameter have a decreasing tendency with an increase of the number of sojourns. This means that, in the round-type pattern, the effect of this factor on the trip chaining formation is less than that of the less sojourn type pattern.

In the second step, the linear regression equations for Eq. (15), in which estabishments, persons engaged, and the floor area are regarded as explanatory variables respectively, were examined. Table-4 shows the parameters for those equations by industry. It is evident from this table that the fitness in the case of persons engaged

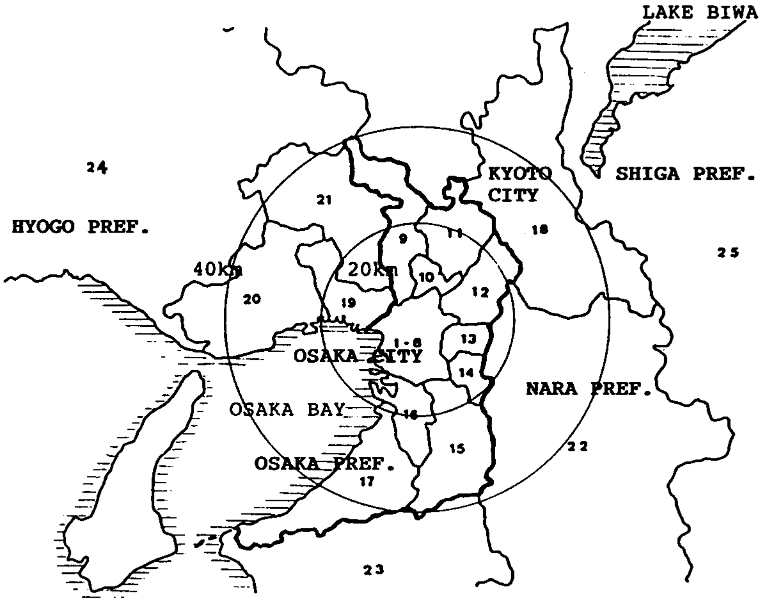


Figure 2. Zoning of the Osaka metropolitan area

Table 2. The estimated values of parameters of a priori probability (by the number of sojourns and by the number of cycles)

$$P^{i}_{lj}=\alpha^{i}_{l}({}^{i}w_{l})^{\beta_l}({}_{i}A_{j})^{\theta_l}\,t_{ij}^{-\gamma_l}$$

No. of cycles	No. of sojourns / parameter	1	2	3	4	5	6	7
1	α 1	69.970	27.370	9.095	3.546	12.870	1.633	1.004
	β 1	–	1.373	0.575	0.248	1.237	1.397	–
	θ 1	0.822	9.757	0.771	0.829	0.549	0.482	0.565
	γ 1	1.409	1.078	0.887	0.841	1.055	0.495	0.278
2	α 2		118.800	8.570	69.090	48.020	2.162	*
	β 2		0.785	-0.558	0.394	0.610	0.015	
	θ 2		0.517	0.400	0.739	0.344	0.382	
	γ 2		1.863	1.570	1.570	1.706	0.933	
3	α 3			55.670	9.2570	10.650	*	*
	β 3			0.828	0.858	0.364		
	θ 3			0.801	0.362	0.095		
	γ 3			1.384	1.086	1.708		
4	α 4				118.100	*	*	*
	β 4				0.822			
	θ 4				-0.173			
	γ 4				2.359			

(note) * ; the samples of those travel patterns are neglected.
\ ; those travel patterns do not exist from their definitions.

Table 3. The coefficient of correlation of a priori probability by the number of sojourns

No. of sojourns	Coefficient of correlation
1	0.8159
2	0.7505
3	0.6791
4	0.7821
5	0.6881
6	0.4046
7	0.3173
Total	0.6544

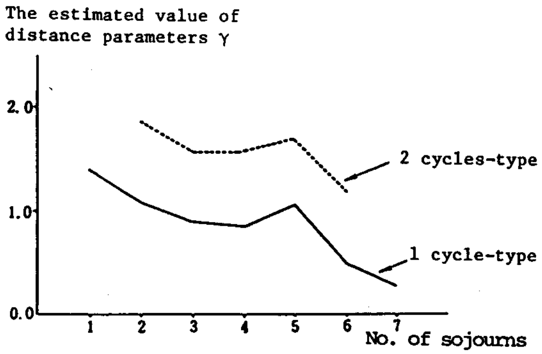


Figure 3. The estimated value of distance-parameter

Table 4. The parameters of the linear regression equation for business trip chains by industry

r^2: Coefficient of correlation

Explanatory variables	Industry	a	b	r^2
Establishments	Construction	-439.3	5.5255	0.6422
	Manufacturing	1297.2	0.8370	0.4390
	Wholesale	-1210.7	3.6023	0.9558
	Retail Trade	211.7	0.6043	0.8557
	Services	-1415.7	1.8677	0.8738
	Others	-1998.3	4.3504	0.7812
	Total	393.1	1.0073	0.5644
Persons engaged	Construction	950.7	0.1748	0.8429
	Manufacturing	-754.7	0.1519	0.8391
	Wholesale	421.1	0.1928	0.9778
	Retail Trade	1307.7	0.0644	0.9042
	Services	-593.4	0.1604	0.9291
	Others	584.5	0.1178	0.9778
	Total	220.2	0.1386	0.8778
Floor area	Construction	615.6	0.0161	0.6443
	Manufacturing	2037.9	0.0003	0.2221
	Wholesale	-34.3	0.0095	0.9146
	Retail Trade	1538.1	0.0022	0.7648
	Services	1828.3	-0.0000	0.1619
	Others	754.2	0.0022	0.6141
	Total	943.6	0.0025	0.5089

Table 5. The parameters of the probability of determining the number of sojourns by industry [$\Pr(s) = \kappa\nu^s$]

Industry	κ	ν
Construction	1.94504	0.32999
Manufacturing	0.88809	0.49932
Wholesale	0.73377	0.58115
Retail Trade	1.08007	0.46960
Services	1.20040	0.44821
Others	0.91655	0.52483
Total	1.03095	0.48880

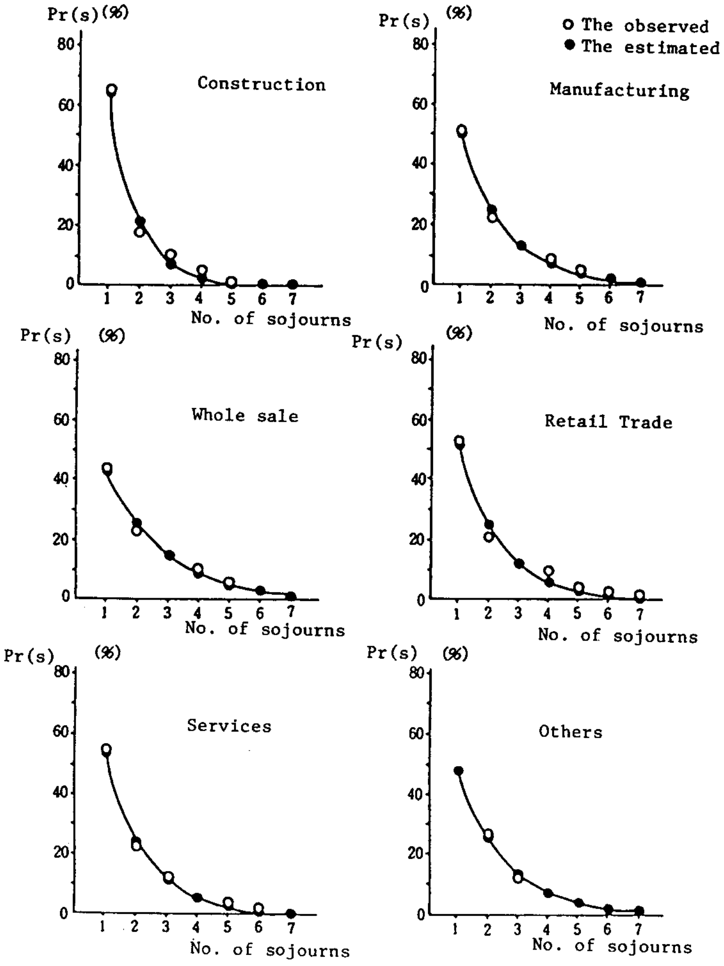


Figure 4. The comparison between the observed and the estimated of the probability of determining the number of sojourns

is the best of those cases.

Table-5 shows parameters of the probability of determining the number of sojourns by industry, and Figure-4 represents the comparison between their observed values and the estimated values. Through our previous studies on business trip chainings, such a probability has been found to be expressed as an exponential curve of the number of sojourns empirically and theoretically.

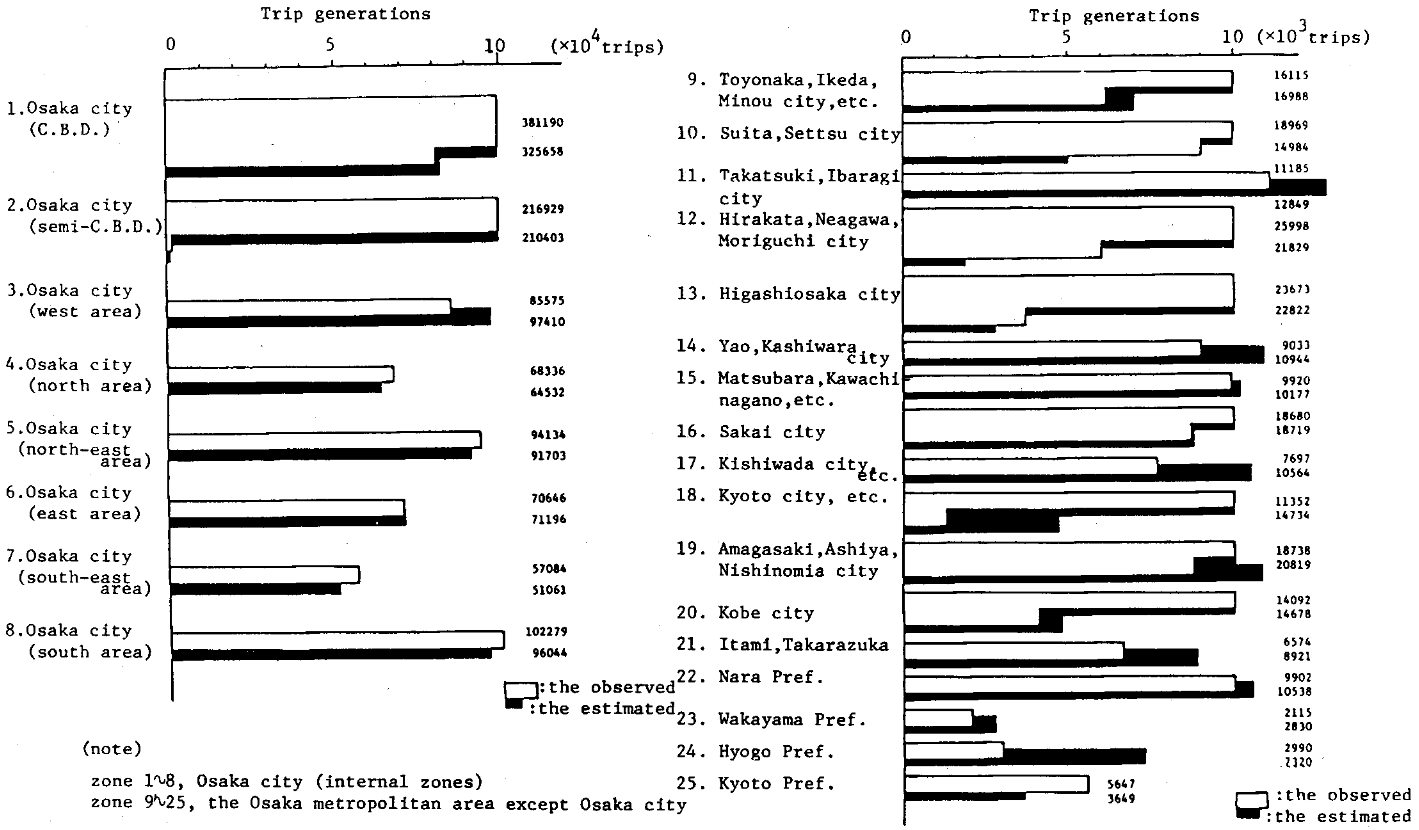
The results shown in both Table-5 and Figure-4 lead to the same conclusions as those of the previous investigations. That is to say, the exponential curves reflect the characteristics caused by the differences of business conduct between industries. For example, as Construction and Manufacturing usually have a small number of sojourns because much duration time is required for each sojourn, their curves make a steep gradient, while Wholesale and Retail Trade have gentle gradient curves because of a large number of sojourns.

In the third step and the fourth step, business trip generations were estimated. After the (ℓ, j) cell of the cycle-sojourn zone distribution for the trip chains having S sourns from the i-th base zone is estimated by using Eq. (22), trip generations can be obtained by substituting those estimated values for Eqs. (4), (5), and (6). Figure-5 shows the comparison between the observed trip generations and the estimated ones for each of zones in the Osaka metropolitan area. It can be found from this figure that, as a whole, the fitness of the model is satisfactory. Also, the coefficient of correlation between the observed and the estimated is 0.9964.

6. Conclusion

The focus of this study has been on incorporating trip chaining into travel demand analysis, and on developing a trip chaining model for an estimation of trip generation. A model was proposed in this study which improves the existing model to represent trip chaining behaviours more explicitly. The validations of this model in travel demand analysis are that it has a capability to explain the derived nature of travel demand due to the various kinds of business activities taking the interaction between base and sojourn into consideration. Also, it describes cycle-sojourn zone distribution, which is useful for clarifying the structure of trip chaining. Through its application to business trip chain data in the Osaka metropolitan area, it was found that this model is superior to the existing trip generation model, not only for its fitness but also for its persuasive power.

However, the model that has been presented remains to be refined in many ways such that it will more realistically represent various aspects of trip chaining behaviour. In particular, the modelling of the sojourn zone choices in trip chaining must be improved in order to consider the effect of the interaction between sojourns on such



(note)

zone 1∿8, Osaka city (internal zones)
zone 9∿25, the Osaka metropolitan area except Osaka city

Figure 5. The comparison between the observed and the estimated of business trip generations

decision making. The concept of the prospective utility in a destination choice model may be promising for solving this problem. (See Kitamura, 1984)

An extension of this model to modal split also remains as an important task. This pertains to the development of a modal split model of the pre-distribution type by a trip chaining approach. From the previous examination of modal split for business trip chain data, we can find that the ratio of a car-use in the first trip in a trip chain tends to become larger with an increase of the number of sojourns. This implies that a trip maker may expect to decide his mode from the viewpoint of the temporal and spatial circumstances related to his business activities in that day. Then, by considering the differences of the probability of determining the number of sojourns between modes such as a car versus others, this tendency of modal split in trip chaining may be able to be represented in the travel demand model.

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