SPATIAL DIFFUSION OF INNOVATIONS

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Abstract The present study investigates innovation diffusion as equivalent to birth-type diffusion. First, the work of Hägerstrand, the substantial initiator in this field, is evaluated in Chapter 2. In Chapter 3, his explanatory framework is validated concerning diffusion phenomena dependent upon the communication process, taking as two examples the 1771 Okagemairi and the Spanish influenza epidemic. In Chapter 4, the examples of electricity supply companies and NHK radio stations reveals that an alternative explanatory framework different from Hägerstrand's should be prepared for diffusion phenomena dependent upon the adoption process. In Chapter 5, a more comprehensive explanatory framework is presented on the basis of the preceding chapers' discussions, which embraces Hägerstrand's explanatory framework and regards entrepreneurial and household innovation diffusion as a chain of events. This explanatory framework, to some extent, follows Brown's, but the author presents as integrated approach further incorporating spatial analysis based on the relational view of space.

1. Introduction

Socio-human phenomena are manifested as the result of human behaviors. This is unexceptionally true, even of phenomena with which human geography is concerned. Since human geography has usually studied various kinds of geographical phenomena on the basis of aggregated unit areas such as census tracts, this point has not been well recognized. The one exception may be location theory, which attributes individual humans' purposeful behaviors to economic rationality, and which on this assumption succeeded in predicting expected spatial patterns of economic activities, using deductive inference and mathematical methods.

When we seek to explain the real world by location theory assuming the uniform space, however, a discrepancy occurs between the real world and the location theory's world. Two different viewpoints exist on how to deal with this discrepancy. The one, taking what the theory points at as a probe and regarding deviation from it as a significant geographical variation, considers the explanation of the deviation as a major task of geography. The other viewpoint, ascribing causes of deviation to the inappropriateness of the original assumptions and revising them to conform to actual human behaviors, strives to reconstruct the theory.

If we use theory positively, of course, the latter viewpoint ought to be supported. The critical points which must be considered here are whimsical human behavior and the resultant incidental occurrence of phenomena. If incidental factors are appropriately taken into account in building the theory, quantitative analysis of socio-human phenomena may not be altogether unreasonable. A pioneering work in this field is Hägerstrand's (1953) on spatial diffusion, employing probability theory. The present study is concerned with analyzing quantitatively the distribution change of socio-human phenomena through spatial diffusion research.

2. Background and aims

Spatial diffusion research

In geography, which is interested in the locational pattern of events, spatial diffusion research has become increasingly important with the recognition that similar spatial patterns can be produced through quite different processes (Eichenbaum and Gale, 1971). T. Hägerstrand's (1953) "Innovationsförloppet ur Korologisk Synpunkt" , translated into English with the title of "Innovation Difusion as a Spatial Process" (Pred, 1967a), paved the way for a branch of spatial process, which aims at investigating the mechanism producing spatial patterns. Thus spatial diffusion research has been established as a subfield of spatial process. Spatial diffusion research differs from cultural geography, which describes diffusion of individual cultural elements such as houses and language, and then delineates the culture area. Rather, spatial diffusion research aims at elucidating the generating mechanism that produces the spatial pattern of the item being diffused. Though Hägerstrand himself confessed that he had been given a hint by the work of Ratzel, a traditional diffusionist (Noma, 1975), his reflection on the sterile cross-sectional approach adopted by Swedish geography convinced him of the need for development of a genetic-quantitative geography through the study of the movement of points or lines, the components of distribution. As a result, Hägerstrand's work appeared, dealing with the evolution of human geographic phenomena in terms of process (Pred, 1967a, pp. 304-305).

Spatial diffusion is defined as a phenomenon in which an event spreads from one or a few points of origin within a given area through time (Brown, 1968, p. 2). It is characteristic of the spatial Markov process: the spatial pattern in any subsequent period depends upon that in the immediately preceding period. Spatial diffusion thus defined is classified into two types: relocation-type diffusion and expansion-type diffusion (Fig. 1). The former type occurs when some members in a population at time t change their locations between time t and t+1. Migration is a typical example. The latter type occurs when new members are added to the population between time t and t+1, and are located so as to alter the locational pattern of the population as a whole. Innovation spread is a typical example. The difference between the two types is as follows: in the former the event being diffused actually moves from one location to another, while in the latter the outbreak of an event being diffused in a place causes a similar outbreak in other places, but no actual movement occurs (Brown, 1968, pp. 2-3).

Diffusion items considered include point, linear and areal ones ranging from various cultural elements to population (Ishimizu, 1972), settlement (Morrill, 1965), epidemics

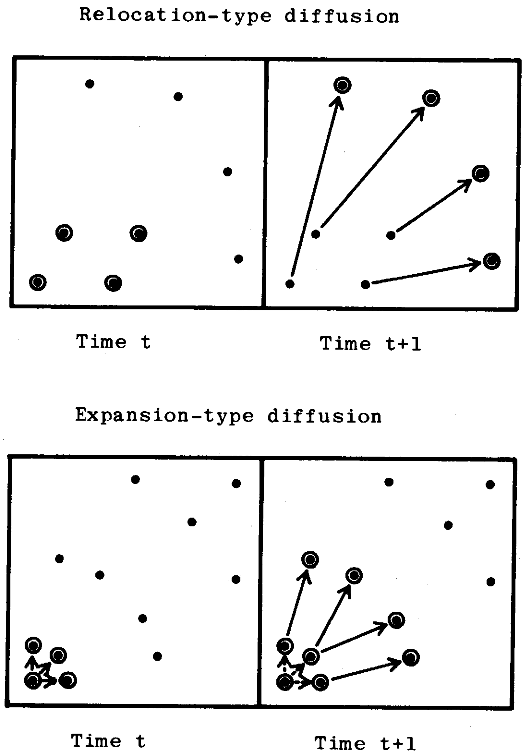

Fig. 1 Types of diffusion (adapted from Brown and Moore, 1969)

(Sugiura, 1975), land use (Fujita, 1973) and transportation networks (Kansky, 1963). In particular, locational diffusionists since Hägerstrand have dealt with innovation and its relevant information, which are much involved with social change. Innovation in the present study comprehensively means new knowledge, thechniques, goods, institutions and facilities and so on.

The locational diffusionist's viewpoint is succinctly expressed in Hägerstrand's own statements. Methodologically, the essential thing is "not to consider the situation at time 1700, time 1800, time 1900, etc. . . . (, but to) consider the situation between the time t and t+dt" (Pred, 1967a, p. 2). In addition, ". . . the main stress is not placed on the initial appearance of a change, . . ., but rather on subsequent events" (Pred, 1967a, p. 5); consideration should be focused on "how does the adoption of an innovation become widespread once it has come into a "settlement" ?" (Pred, 1967a, p. 5). Accordingly, "the problems associated with the origins of these cultural elements and the conditions surrounding their invention are themselves not illuminated by a diffusion study of the type presented in this book" (Pred, 1967a, p. 13).

Now, "changes in spatial distribution of cultural element occur in conformity to certain undiscovered principles. In searching for these principles, it is of no importance that the phenomena considered have a traditional place in geography", because "the objects themselves are not the center of observation" but are used only "as indicators of people's ways of behaving with regard to the relative location of dwelling places" (Hägerstrand, 1952, p. 4). Thus "the first claim for an indicator is not that it is of "geographical importance" but that the data are complete for more than one moment in time and capable of quantitative analysis" (Hägerstrand, 1952, p. 4), and additionally "capable of adoption by quite a large number of people within the study area " (Pred, 1967a, p. 11). Moreover "indicators are not in themselves of any special interest", and "the same is true of the specific area within which the indicators will be examined" (Pred, 1967a, p. 14), because "our aim is not to describe or analyze a region, but to throw some light on a general problem" (Pred, 1967a, p. 4). That is, the locational diffusionist "is concerned with the analysis of a mechanism of the diffusion of innovations as a spatial process" (Pred, 1967a, p. 1), which belongs to the branch of "geography of cultural behavior" (Hägerstrand, 1952, p. 4).

Outlime of Hägerstrand's work and its contributions

Hägerstrand investigated the mechanism of spatial diffusion of innovations in southern Östergötland province of Sweden, using agricultural indicators such as grazing improvement subsidies granted to farmers with cultivated holdings of less than 10 hectares, bovine tuberculosis control and soil mapping, and general indicators such as postal checking services, automobile ownership and telephone subscribers. Comparison of year-by-year distributions of these innovations' adopters in the 1900's—1940's led him to describe the characteristics of their diffusion as follows (Pred, 1967a, pp. 133-134):

Stage 1: Local concentrations of initial acceptances (initial agglomerations).

Stage 2: Radial dissemination outward from the initial agglomerations is accompanied by the rise of secondary agglomerations, while those original centers simultaneously continue to condense.

Stage 3: The growth ceases (seturation stage).

In order to explain such a spatial diffusion process, Hägerstrand presented a Monte Carlo simulation model (Hägerstrand, 1965; Pred, 1967a). The model mainly consists of four parts: the Mean Information Field (MIF) operationally defining the distance-decay spread of information about innovation caused by the neighborhood effect; five resistance classes operationally defining the sum of information or the frequency of contact with adopters necessary to overcome resistance to innovation; real-world population distribution; barrier effects—impediments to communication by obstacles such as lakes and forests. After comparing the real-world pattern of adopters' distribution with the output simulated by the model that replicates information spread process by random numbers, Hägerstrand confirmed the appropriateness of his own explanatory framework.

Hägerstrand's contributions to innovation diffusion research are summarized in the following two aspects (Brown and Moore, 1969). The first is a conceptualization of the diffusion process of innovation. Adoption of an innovation is primarily the outcome of a learning process through face-to-face contact, and it consists of the two sub-processes of communication and adoption. Hägerstrand suggested the appropriateness of an analysis focusing upon the elements which control the flow of information about innovation. Information about innovation surely spreads through a communication network. Since actual geographic space is not isotropic, however, the communication network will be variously transformed by physical and social barriers. In contrast, the realization of innovation adoption is time-lagged according to the adopter's economic, social and psychological characteristics. Under such a mechanism the neighborhood effect produces a spatial diffusion pattern of innovation aggregated from individuals' adoption behaviors: new adopters usually appear near previous ones. The neighborhood effect is thus a principle which empirically accounts for a fact that innovation and information are highly likely to be transmitted to neighbors of earlier adopters (Brown and Cox, 1971). Strictly speaking, it is a principle which accounts for the spatially contagious diffusion tendency through communication networks among neighbors.

Thus Hägerstrand's conceptualization has made possible an articulated analysis, focusing upon 1) communication networks, 2) barriers impeding communication, and 3) personal resistance levels. This conceptualization is shown in Fig. 2, where solid line arrows are taken into account in Hägerstrand's model. His attention to personal communication corresponds to the sociologist's general view (Rogers, 1962, p. 99): impersonal information sources are most important at the awareness stage, while personal sources are most important at the evaluation stage in the adoption process, which in turn consists of five stages: awareness, interest, evaluation, trial and adoption.

Hägerstrand's second contribution is the creation of an operational model of spatial diffusion. His Monte Carlo simulation model, where elements relevant to information spread are divided into random and non-random ones such as distance, population distribution and barriers, has made it possible to deal with the diffusion process operationally in the spatial dimension. Though his idea that information spread in distance-decay fashion but at random directionally is unique, it is an insight on human behavior and geographic phenomena that must be considered, as Pred (1967a, p. 307) has pointed out: "Many ingredients of individual human behavior are causally so complex that their aggregate spatial expression is usually randomly determined within certain constraints (stochastically determined), even though the decisions behind this behavior are not randomly motivated." Needless to say, an application of the stochastic model to socio-human phenomena requires cautious examination. In addition to the appropriateness of the Monte Carlo method, nevertheless, Hägerstrand's idea that the black-box part of complicated human behaviors can be conveniently assumed to be the random element has greatly influenced some research branches concerned with

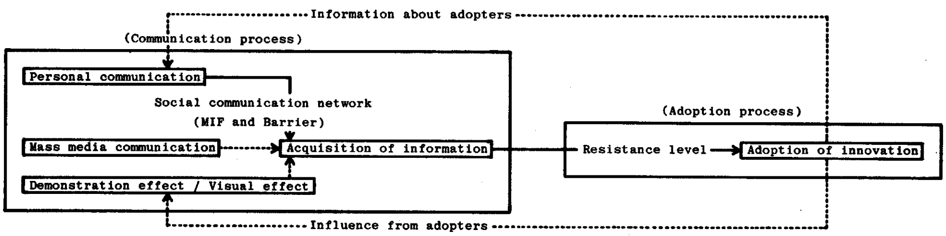

Fig. 2 Conceptualization of innovation diffusion by Hägerstrand

locational process. In addition, his first extensive use of the Monte Carlo method in social science has paved the way for an introduction of experimental methods to human geography.

As the preceding discussion suggests, Hägerstrand's work in terms of the way of thinking differs greatly from the area study forming the major research theme of 1940's-1950's geography as well as from traditional cultural geography. In particular, the theory-orientedness led up to the quantitative revolution in geography, which began at the University of Washington in the 1950's (Sugiura, 1985). And, while pointing out the important role of information in decision-making, Hägerstrand recognized that the whole distribution pattern resulting from the spatial diffusion process might be ultimately ascribed to individuals' decision-making, at the center of the "field". Thus he succeeded in combining micro- and macro-scale phenomena, so that he is also appreciated as a pioneer in behavioral research that lays stress on decision-makers' imperfect knowledge and non-rational behavior (Golledge *et al.*, 1972; Pred, 1967b).

The problem

Hägerstrand investigated not only innovation diffusion in a rural area, but also both interurban and international diffusion of innovations, using automobiles, radio sets and Rotary Clubs as indicators (Hägerstrand, 1952, 1966). As a result, he concluded that innovation diffusion usually depends upon city size and/or distance from adopter-cities on those regional scales. He prepared the same explanatory framework based on the communication process to account for the empirical regularities on these scales. He suggested that hierarchical diffusion from larger to smaller cities, which was usually observed during the primary and middle stages, could occur through the social communication network corresponding to the hierarchical structure of an urban system. The hierarchy effect is a principle which empirically explains that innovation and information are likely to spread from larger to smaller cities through a hierarchical communication network (Brown and Cox, 1971). Spatially contagious diffusion markedly observed after the middle stage was attributed to the neighborhood effect as well.

Taking into account these findings, Hudson (1969) built a model on innovation diffusion through a central place system, and Pedersen (1970) conceptualized the innovation diffusion process through an urban system. Unfortunately their work placed so much emphasis on the communication process that the adoption process was rarely referred to, and factors other than information were insufficiently considered. For example, in the case of a shopping center whose opening would depend to a great extent upon some economic factors, even if the communication process exists before the adoption process, the former does not necessarily emerge explicitly. Or, rather, timing in adopting this kind of innovation would be appropriately accounted for by market size (Cohen, 1972; Sheppard, 1976; Webber and Joseph, 1977). It seems therefore necessary to analyze not only information flows between entrepreneurs but also their investment behavior and perceptions of the market.

New crop diffusion is a similar example. Even if a new crop makes farmers more profit than a prevailing crop, requires no special technique and large capital, and permits adoption on a small scale, it would be rare for it to be adopted immediately. Followers will carefully watch the pioneer's "experiment". After making sure of the result, they then gradually imitate the innovation. It will take a certain amount of time for most of them to get information about the new crop and to adopt it. If its adoption involves great risk, the adoption process rather than the communication process will play the most important role in the whole diffusion process.

The preceding discussion indicates that Hägerstrand's explanatory framework overridingly emphasizes the information factor (see also Sugiura (1976)). But it seems premature to negate all the research products for that reason only. Rather, it is more productive first to identify what this explanatory framework can be applied to, and second to prepare a new explanatory framework for what it cannot be applied to. In line with this view, the validity of Hägerstrand's explanatory framework is examined in Chapter 3 of the present work, taking two examples: the 1771 Okagemairi and Spanish influenza in the period 1918-1921, both of which appear to be epidemic phenomena spreading through personal contact. Since an epidemic phenomenon is rapidly accepted without perception, evaluation and adoption stages, it will be suggested that it serves as a useful geographical tracer in detecting an urban or regional system as a diffusion channel. In Chapter 4, innovation diffusion where a decision to adopt plays an important role in the diffusion process is analyzed from a viewpoint other than Hägerstrand's explanatory framework, taking as examples electricity supply companies and radio stations. The key concepts in analyzing their diffusion are, respectively, market area division and facility location. Based on the results obtained, a more comprehensive explanatory framework for spatial diffusion research on innovation is discussed in Chapter 5. Finally, an analytical approach will be presented along with this framework.

3. Diffusion dependent upon communication process

Introduction

As has been shown by previous substantive studies, there is usually a certain spatial order in the spread of innovation and information over geographical space. Because they spread through communication channels such as an urban hierarchy or an individual's information field, the resultant diffusion pattern is explicable by the hierarchy and/or neighborhood effects. It is conceivable that the spatial diffusion pattern of innovation and information corresponds to the configuration of an urban or regional system, if the system concerned is defined as follows: a set of cities or regions which are interdependent in such a way that any significant change in social, economic, demographic or cultural attributes of one member city or region will directly or indirectly bring about some alteration in the social, economic, demographic or cultural attributes of one or more other set members (Pred, 1977). Though this proposition is too naive to accept in the case of an innovation whose diffusion involves a complicated decision-making process, it is useful to verify it in the case of an innovation whose diffusion mainly depends upon the communication process. This chapter is concerned with examination of the structural correspondence between (cultural) epidemic diffusion and an urban or regional system as a diffusion channel, taking as examples a cultural epidemic—the 1771 Okagemairi or group pilgrimages to the Ise Shrine—and the epidemic of Spanish influenza in the period 1918-1921. These two examples are selected principally on the basis of data availability pertinent to the purpose. This selection unexpectedly resulted in making it possible to test the validity of the above-mentioned proposition in early and recent modern times on different communication levels.

Spatial diffusion of the 1771 Okagemairi

On the Okagemairi

According to Fujitani (1958a,1958b, 1967), Shinjo (1964) and Nishigaki (1973), the Okagemairi can be summarized as follows. The custom of visiting the Ise Shrine once in one's lifetime was widespread among the Japanese during the Edo era (1603-1867). Because of the feudal regulations most of the pilgrims were patriarchs; it was impossible for their wives and children or employees, both economically and in terms of status, to visit the Ise Shrine, except for secret pilgrimages called Nukemairi. The Okagemairi is, so to speak, a large-scale Nukemairi that rapidly spread over the country within a short period. Historically the Okagemairi is reported to have taken place in a cycle of about sixty years.

The Okagemairi usually began with rumors about the falling of the Ise Shrine's charms from the heavens; then wives and children or employees joined in the group pilgrimage. Since patriarchs were unwilling to tolerate these pilgrimages without official permission, however, they were forced to taravel with no money. People along the route to the Ise Shrine gave alms to them, for example, offering food and money or free lodging. Consequently it came to be possible for people who could not make a pilgrimage even in an ordinary form of Nukemairi to visit the Ise Shrine. To sum up: the Okagemairi, which is understood as a cultural epidemic phenomenon in a short period caused by mob psychology, is distinguishable from the ordinary Nukemairi in respect of its nature and scale. Nationwide Okagemairis took place in 1705, 1771 and 1830. The present study deals with the 1771 Okagemairi because there are data susceptible to quantitative analysis, and because the number of home-provinces of visitors is the largest among the three Okagemairis. The data's source, its close examination and its processing are presented in Sugiura (1978a). The study area covers 62 unit areas or provinces: all except Ezo (present-day Hokkaido), Mutsu, Dewa, Sado, Oki, Iki and Tsushima.

It is said that the number of visitors to the Ise Shrine was, on the average, four to five hundred thousand a year in the Edo era (Shinjo, 1964, p. 929). In contrast, a total of two hundred thousand people joined in the 1771 Okagemairi within a mere four months. It is recorded that as many as eighty-four hundred people ferried across the Miya River in Ise province on May 10, the peak day (Nishigaki, 1973). Fig. 3 shows the diffusion process of the Okagemairi in ten-days unit. The Okagemairi originating from Yamashiro on April 7 spread to the inner Kinki district and its surrounding provinces in late April, and to some provinces facing the Inland Sea of Japan by early May. In late May the Okagemairi spread to provinces of the Chugoku district (except the northeastern part) and a few provinces of the Kyushu district as well as provinces of the Hokuriku, Tokai and Shikoku districts, further leapfrogging to Musashi province of the Kanto district. By late

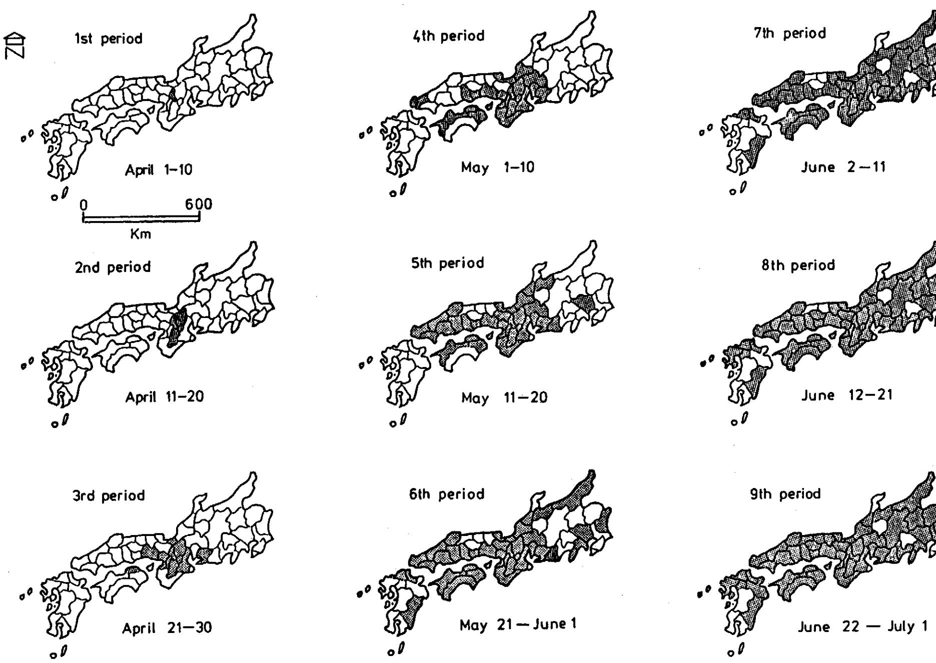

Fig. 3 Spatial diffusion process of the 1771 Okagemairi

June the Okagemairi ultimately spread to 53 provinces.

Monte Carlo simulation of diffusion process

In this sub-section the information diffusion process from Yamashiro province, the origin point of diffusion, will be simulated with the aid of the Monte Carlo method. The information field, the essential part of the simulation model, is estimated by the following gravity model, whose details are presented in Sugiura (1978a):

$$I_{ij} = KP_i \, P_j \, / \, d^b{}_{ij} \qquad (i \neq j)$$

where I_{ij} is information flow between provinces i and j; P_i and P_j are populations of provinces i and j as of 1756; d_{ij} is distance between provinces i and j; K is a constant; and b is a distance parameter whose best fit value will be heuristically estimated by the iterative method.

Fig. 4 shows the simulation algorithm. Goodness-of-fit is tested by two methods: 1) a correlation coefficient which is used to measure the correspondence between the actual date of diffusion and the simulated date or generation; 2) a coefficient of spatial association (Sorensen, 1974) which is used to measure the spatial relationship between two areally distributed sets of points—that is, provinces with Okagemairi participants and those with no Okagemairi participants—in each generation.

In the present study the following simulation models are constructed on the basis of both trend surface analysis of the date of diffusion and the investigation of nine provinces with no Okagemairi participants (see Sugiura (1978a) for details):

1) Distance parameter for the land route is set at 3.0.

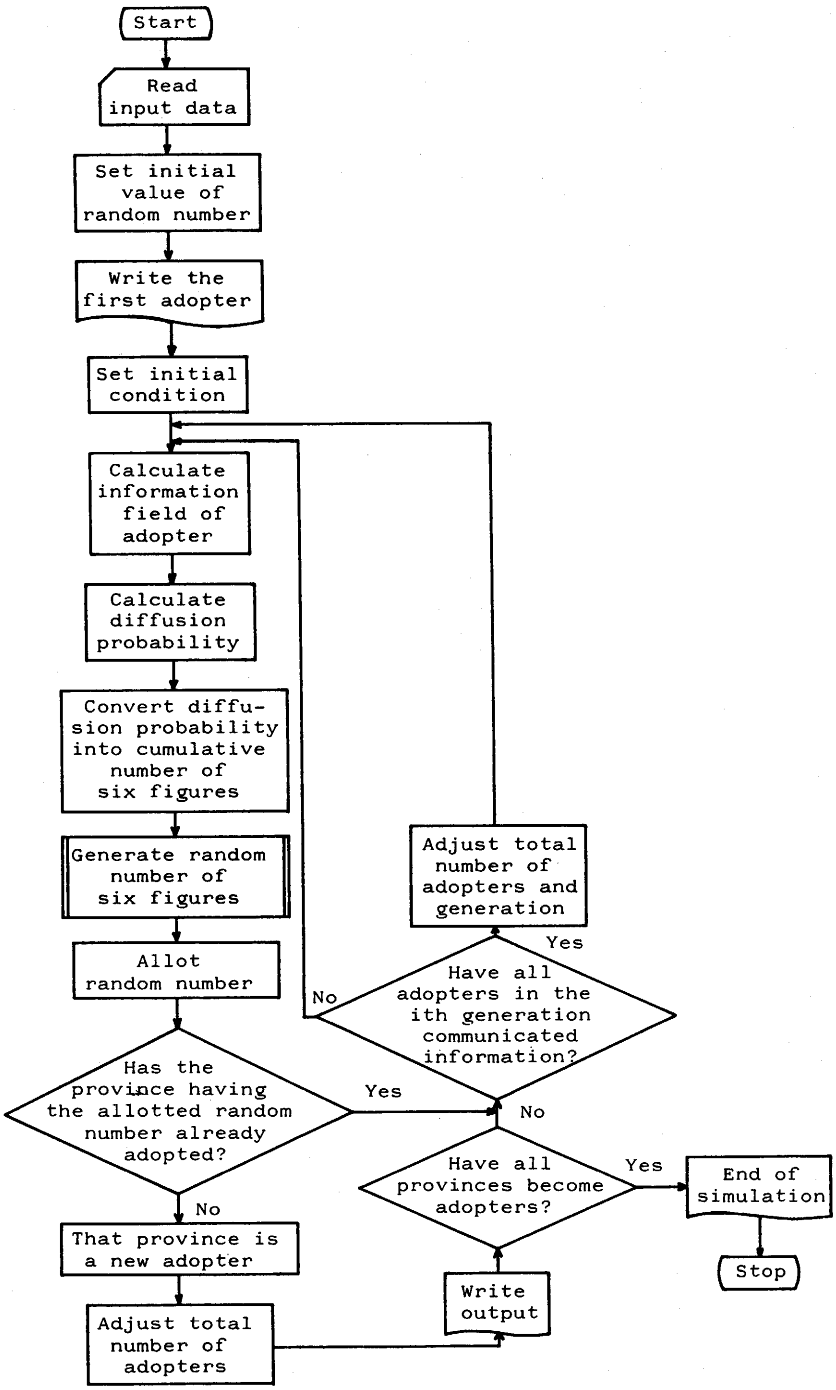

Fig. 4 Flowchart of simulation

2) Taking into account the reduction of distance friction by the Inland Sea line, distance parameter is set at 2.5 when information spreads between seventeen provinces facing the Inland Sea of Japan.
3) Taking into account the reduction of distance friction by the Hokuriku-Nipponkai line, distance parameter is set at 2.75 when information spreads between six provinces north of Wakasa.
4) Taking into account the barrier effect of the Chubu mountains, distance parameter is set at 3.25 when information spreads between three mountainous provinces of Hida, Shinano and Kai and other provinces.
5) The seven provinces of Noto, Hida, Awa, Kazusa, Shimosa, Kai and Suruga do not accept the Okagemairi until they receive information twice; this is because believers in the Jodoshin and Nichiren sects religiously resisted the Ise faith associated with the Okagemairi.

The outline of Model I mainly consists of item 1) above; that of Model II consists of items 1)-4); and that of Model III consists of items 1)-5). The results are shown in Table 1. Model III had the best goodness-of-fit in terms of both correlation coefficient and coefficient of spatial association. Fig. 5 shows the simulation output of Model III. Detailed examination of results is given in Sugiura (1978a). It is concluded that Model III has successfully replicated the actual diffusion process of the Okagemairi. The results of the above analysis are summarized as follows:

1) The Okagemairi spread spatially contagiously from Yamashiro province or the origin point of diffusion. This diffusion pattern was mainly produced by information transfer about the Okagemairi from Yamashiro to its surrounding provinces; the Okagemairi also spread through communication by ordinary visitors on their way home from the Ise Shrine, and by the demonstration effect as passage of Okagemairi participants spontaneously induced new participants in provinces along the routes.

Table 1 Goodness-of-fit of Models I -III

Period	Number of provinces	Model I (Distance parameter)							Model II	Model III
		1.0	1.5	2.0	2.5	3.0	3.5	4.0		
II	4	0.0445	0.4571	0.2670	0.2670	0.2401	0.2670	0.2670	0.2401	0.2401
III	12	0.0402	0.2310	0.2790	0.2790	0.3368	0.5361	0.2721	0.3922	0.3922
IV	23	0.0403	0.0276	0.0920	0.3410	0.3758	0.3673	0.1960	0.5381	0.6239
V	33	0.2777	0.2771	0.4021	0.4353	0.4461	0.3350	0.2002	0.6082	0.6865
VI	41	0.5917	0.5491	0.5292	0.4440	0.4656	0.3699	0.1637	0.6280	0.7078
VII	47	0.6963	0.6902	0.7444	0.8363	0.7376	0.5754	0.5260	0.7809	0.7684
VIII	50	0.8148	0.7593	0.8069	0.7517	0.7120	0.6508	0.5440	0.7356	0.8325
IX	53	0.8646	0.8454	0.8633	0.8240	0.8011	0.7540	0.7363	0.7466	0.8738
Correlation coefficient		0.3436*	0.5388***	0.5454***	0.6711***	0.6948***	0.6679***	0.6421***	0.7518***	0.7071***

*** Significant at the 0.001 level
* Significant at the 0.05 level
(Using coefficient of spatial association and correlation coefficient)

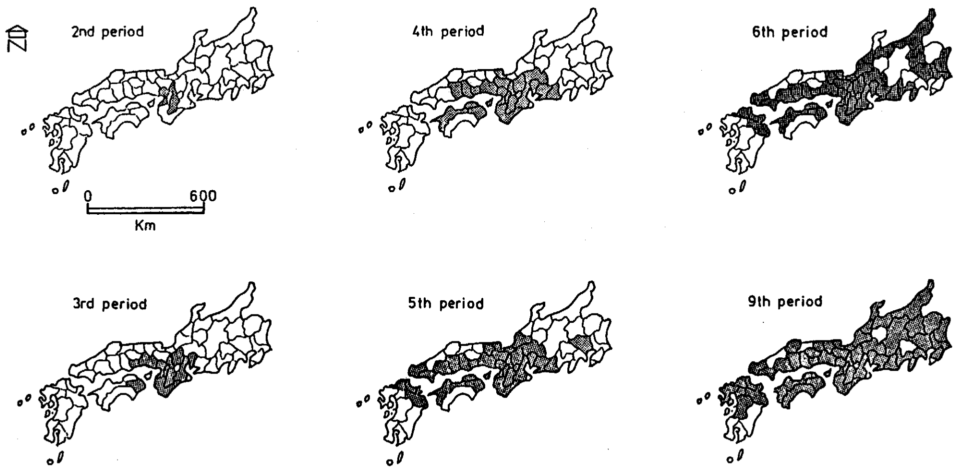

Fig. 5 Output of Model III

2) On the other hand, even in those days when urban or regional systems were not sufficiently integrated to promote hierarchical diffusion, the leapfrogging spread to Settsu and Musashi provinces suggests that the effect of population size was partially in operation; but the determinant in warping the ellipse-like diffusion pattern seems to have been a short-circuit effect through the Inland Sea and Hokuriku-Nipponkai lines rather than the effect of population size.
3) Analysis of provinces where the Okagemairi spread slowly or where participants did not appear reveals that the Chubu mountains operated as a physical barrier, and that there were religious resistances among the Jodoshin and Nichiren sects to the Ise faith in some eastern provinces.
4) Especially with reference to item 2) above, therefore, it may safely be said that the Western Japan regional system, whose largest cities were Osaka and Kyoto, operated as a diffusion channel in the epidemic of the 1771 Okagemairi.

Relationship between the 1771 Okagemairi diffusion and the regional system

There rarely exist comprehensive data suitable to investigate the Japanese regional system of early modern times. In the case of the Edo era, for example, such is the state of things that we can only infer the regional system by roughly sketching the Osaka and Edo (present-day Tokyo) hinterland based on origin ports from which commodities were shipped there. Recently, however, quantitative economic history has steadily tackled this problem by discovering new data and analyzing them quantitatively. The work of Iwahashi (1981), Miyamoto (1981) and Yamazaki (1983), who illustrated regional linkage in terms of (rice) price fluctuation, may enable us to confirm the existence of an integrated Western Japan regional system to some extent; such a system was implicitly assumed in estimating the parameters of the simulation model. In this sub-section rice price fluctuation data shown in Miyamoto (1981) are analyzed in order to elucidate the regional system in the latter half of the 18th century, during which period the 1771 Okagemairi took place. Cluster analysis is applied to the correlation matrix of the annual

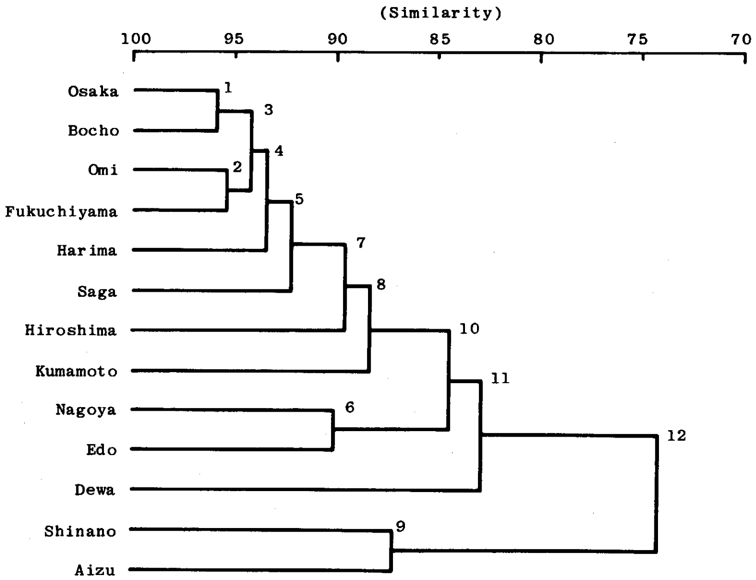

Fig. 6 Dendrogram of correlation matrix of annual rate of change in rice prices between thirteen districts during the period 1751-1800

rate of change in rice prices between 13 districts during the period 1751-1800, in order to identify regional groups with similar economic fluctuations.

Fig. 6 shows a dendrogram of the clustering process. The clustering was stopped between the 9th and 10th steps where the second rapid decrease in similarity was observed. As a result, 13 distircts were classified into four groups: 1) a Western Japan group consisting of eight provinces west of Omi; 2) the group of Nagoya and Edo; 3) Dewa; 4) the group of Shinano and Aizu. If two regions are similar with regard to such factors influencing rice production as cultivation technique or weather conditions, then rice prices will be highly correlated between independent local rice markets with no rice transactions. Generally, if two regions' rice prices are highly correlated, it can be assumed that they were closely linked in terms of rice flows. Unfortunately the literature on quantitative economic history has not yet confirmed this assumption with appropriate data; nor does the present study. Nevertheless, the result is of interest. The clustering process of the Western Japan group seems to indicate that the Western Japan regional system had been, to some extent, integrated around the core area of the Kinki and Chugoku districts, particularly Osaka and Bocho linked together; the nearer to Osaka the district is situated, the earlier it joins the group. This fact implies that the simulation attempted in the preceding sub-section was correct in attributing a short-circuit effect to the Inland Sea line. It is also of great interest that other regional groups' linkages with the Western Japan group become weak in direct correlation with (time-) distance from Osaka, in the following order: Nagoya and Edo; Dewa, which was linked with the Kinki district through the Hokuriku-Nipponkai line; Shinano and Aizu. The appropriateness of the barrier effect assumed for communication between mountainous provinces and others was substantiated by the fact that highly isolated districts such as Shinano and Aizu joined the Western Japan group only at the final stage. The fact that Edo did not yet form one group subordinating Eastern Japan supports the popular view that the Eastern Japan regional system was not so closely integrated as the Western Japan regional system was (Toyoda and Kodama, 1969).

Thus the following conclusion is drawn from the above analysis: the Okagemairi spread through the regional system operating as a diffusion channel, rather than in a simple distance-decay fashion from the origin point of diffusion.

Spatial diffusion of Spanish influenza, 1916-1926

On Spanish influenza

Spanish influenza is named after Spain, the origin point of the epidemic. It was a rare epidemic in history in that twenty-three million people died and six hundred million were ill all over the world. The first outbreak was reported in the battlefield of France during World War I, in spring of 1918. Having spread among the Allies, the epidemic was immediately brought to all the European countries by the troops and then swept over the world by the end of the year 1918 (Kanemitsu *et al.*, 1966, pp. 482-483). There were some symptoms in Japan from late August to early September, 1918. It immediately spread over the entire country, and three successive waves of prevalence had taken place by July 1921. The existence of pathogenic viruses had not yet been discovered, and the level of medical treatment was such that influenza germs irrelevant to the etiological cause or pneumonia vaccine was misused as influenza vaccine (Nippon Koshueisei Kyokai, 1961, p. 35). Consequently Spanish influenza was the largest-scale epidemic recorded in Japan for both prewar and postwar periods: diseased and dead respectively amounted to 21,168, 398 and 257,363 in the first wave of prevalence from August 1918 to July 1919; 2,412,097 and 127,666 in the second wave from September 1919 to July 1920; and 224,178 and 3,698 in the third wave from August 1920 to July 1921.

It is said that the epidemic was first carried to Japan by crew members of warship returning to Yokohama Port from the South Seas in early May 1918 and by passengers on a ship entering Yokohama from North America on September 2, 1918, on which many diseased persons were observed. According to the popular view, however, "the epidemic of Spanish influenza did not exhibit any clear diffusion process in Japan, so that the path of invasion from abroad and the first outbreak place were entirely unknown" (Naimusho Eiseikyoku, 1922, p. 84; Nippon Koshueisei Kyokai, 1961, p. 36). But examination of both the first outbreaks reported in "The Grippe", a report on Spanish influenza, and "Statistics of Death Causes of the Japanese Empire" (Sugiura, 1977) suggested that the epidemic spread from Western Japan to Eastern Japan (Fig. 7). Thus the purpose of the next sub-section is to clarify the diffusion route of the epidemic.

Factor analysis of regionalization of influenza mortality

The monthly influenza mortality rates for each prefecture from July 1916 to June 1926 were analyzed by S-mode factor analysis in order to investigate the epidemic diffusion process in detail. In factor analysis it is assumed that the observable variable x can be decomposed as:

$$x_i = a_{i1}f_1 + a_{i2}f_2 + \ldots + a_{im}f_m + a_iu_i$$

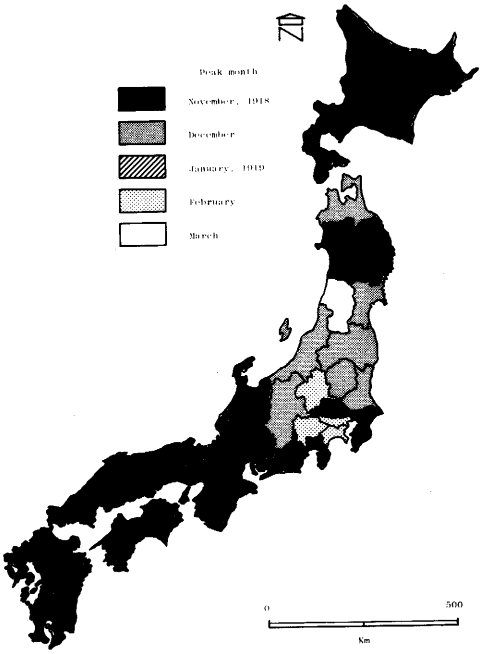

Fig. 7-a Spatial diffusion process of Spanish influenza, 1918-1919

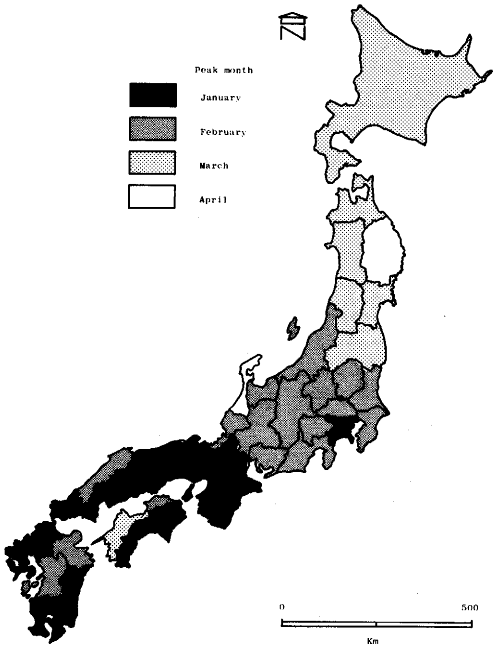

Fig. 7-b Spatial diffusion process of Spanish influenza, 1920

where a_i is factor loading ($i = 1, 2, ..., n$); f_k is factor score ($k = 1, 2, ..., m$); and u_i is specific factor ($i = 1, 2, ..., n$). In this case factors extracted are regarded as summarizing influenza epidemic areas with similar temporal mortality variations, which are interpreted on the base of factor loadings representing correlations between factors and prefectures. Factor scores summarize the temporal mortality variations common to the subsets of prefectures constituting the factor, which may give a clue to the lead-lag relationships between factors.

The 120 (the number of months) $\times$ 46 (the number of prefectures) data matrix was subjected to factor analysis, and three factors with eigenvalues greater than 1.0 were extracted (Table 2). Fig. 8 shows distribution of prefectures with factor loadings greater than 0.5. Detailed interpretation of the three factors is given in Sugiura (1977) through correlation analysis between factor loadings and 11 relevant variables (Table 3). The factors are interpreted as follows. Factor I, accounting for 78.8% of the total variance, is related to the contagious opportunity restricted by the distance from the major ports such as Kobe, Moji, Nagasaki, Shimonoseki and Osaka in the western part of Japan; this factor distinguishes Western Japan from the rest of the country. Factor II, accounting for 8.5% of the total variance, is related to the contagious opportunity corresponding to the hierarchical urban system; this factor distinguishes urban areas from the other areas. Factor III, accounting for 7.9% of the total variance, is related to the variables promoting the prevalence of influenza in a household, that is, temperature, the average

Table 2 Matrix of factor loadings of monthly influenza mortality data

Prefecture	Factor I	Factor II	Factor III
Hokkaido	(0.6212)	0.2872	(0.7100)
Aomori	0.4806	−0.0109	(0.8175)
Iwate	(0.8067)	0.0724	(0.5394)
Miyagi	0.3244	0.3592	(0.8469)
Akita	(0.6914)	0.0057	(0.6918)
Yamagata	0.1693	0.1141	(0.8705)
Fukushima	0.1895	0.4472	(0.8511)
Ibaragi	0.3708	0.4592	(0.7781)
Tochigi	0.3945	(0.5658)	(0.7085)
Gunma	0.2075	(0.6164)	(0.6446)
Saitama	0.2996	(0.7380)	(0.5634)
Chiba	0.2735	(0.7304)	(0.6033)
Tokyo	0.1907	(0.9104)	0.1155
Kanagawa	0.1882	(0.9116)	0.3225
Niigata	0.3876	0.3943	(0.8143)
Toyama	(0.6949)	0.3836	(0.5675)
Ishikawa	(0.8028)	0.1927	(0.5355)
Fukui	(0.8961)	0.2522	0.3044
Yamanashi	0.0630	(0.7977)	(0.5642)
Nagano	0.4886	0.3026	(0.7995)
Gifu	(0.6720)	0.2565	(0.6369)
Shizuoka	0.1841	(0.8026)	(0.5084)
Aichi	(0.5972)	(0.5352)	(0.5605)
Mie	(0.7785)	0.3758	0.4311
Shiga	(0.5159)	(0.7075)	0.4382
Kyoto	(0.6150)	(0.7379)	0.2267
Osaka	(0.5561)	(0.7689)	−0.0179
Hyogo	(0.5866)	(0.7666)	0.0907
Nara	(0.7262)	(0.6366)	0.2369
Wakayama	(0.8118)	0.4362	0.3572
Tottori	(0.6495)	(0.6318)	0.3895
Shimane	(0.8404)	0.2793	0.4353
Okayama	(0.6841)	(0.5888)	0.3770
Hiroshima	(0.7449)	(0.5724)	0.3076
Yamaguchi	(0.6398)	(0.7011)	0.2603
Tokushima	(0.7103)	(0.6105)	0.3099
Kagawa	(0.8424)	0.3656	0.3202
Ehime	(0.8094)	0.3110	0.4512
Kochi	(0.9490)	0.1525	0.2227
Fukuoka	(0.6684)	(0.7154)	0.1042
Saga	(0.8817)	0.4081	0.1420
Nagasaki	(0.6255)	(0.7029)	0.2682
Kumamoto	(0.8469)	0.4268	0.2515
Oita	(0.8776)	0.3051	0.3278
Miyazaki	(0.9238)	0.2477	0.2732
Kagoshima	(0.8557)	0.3612	0.3229
Eigenvalue	36.2299	3.9216	3.6148
Variance	78.8	8.5	7.9

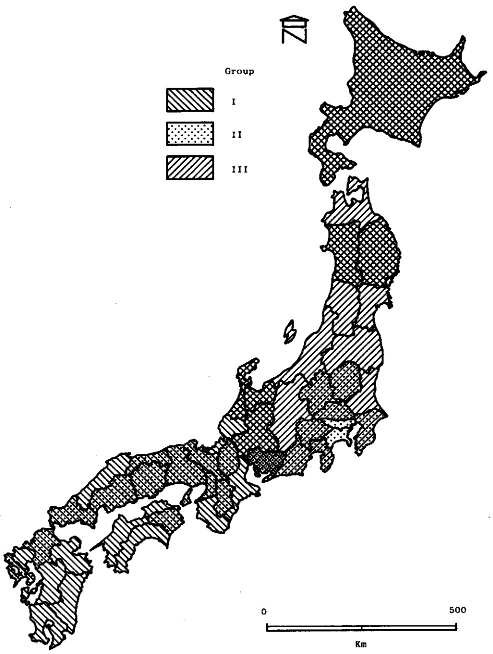

Fig. 8 Grouping of epidemic areas based on factor loadings (greater than 0.5)

number of persons per household, percentage of people under 15 years and over 60 years, personal income and the number of doctors per 1,000 persons; this factor distinguishes Eastern Japan from the rest of the country.

Cross-correlations for lag values from −3 to +3 months between factor scores were calculated in order to clarify the time lead and lag relationships among the three epidemic areas (Fig. 9). It turned out that there was not a marked time lag between the Factor I and Factor II areas. This result suggests that the epidemic in the Factor II area broke out independent of that in the Factor I area. Though the time lead and lag relationship is vague, therefore, Spanish influenza probably invaded via major ports of Western Japan, and via Yokohama Port, the outer port of Tokyo and the largest port in Eastern Japan. Since Factor III appears to be closely associated with Factor II, the epidemic could spread from the Factor II area to the Factor III area two months later.

On the basis of the results of these cross-correlation analysis, therefore, the diffusion route could be presumed roughly as follows: Spanish influenza, which had invaded via the major ports in Western Japan, spread toward the east in a distance-decary fashion; at the same time, it spread into the urban areas, moving down the urban hierarchy from Tokyo via Yokohama Port in Eastern Japan, and then spread from the urban areas (especially the Keihin district) to the whole of Eastern Japan.

Relationship between Spanish influenza diffusion and urban system

Data on the basis of which to analyze the Japanese urban system of the prewar days

Table 3 Correlations between relevant variables and factor loadings of monthly influenza mortality data

Variable	Factor I	Factor II	Factor III
Population size (log)	−0.355*	0.376*	−0.067
Population density (log)	−0.223	0.679***	−0.539***
Distance from Tokyo (log)	0.739***	−0.453**	−0.255
Distance from Osaka (log)	−0.205	−0.363*	0.512***
Percentage of people under 15 years and over 60 years	0.184	−0.502***	0.526***
Average number of persons per household	−0.452**	−0.361*	0.680***
Personal income	−0.178	0.518***	−0.521***
Number of doctors per 1,000 persons	0.115	0.371*	−0.561***
Mean temperature	0.351*	0.424**	−0.727***
Mean diurnal range of temperature	−0.017	−0.105	0.095
Mean relative humidity	0.176	−0.466**	0.269

*** Significant at the 0.001 level
** Significant at the 0.01 level
* Significant at the 0.05 level

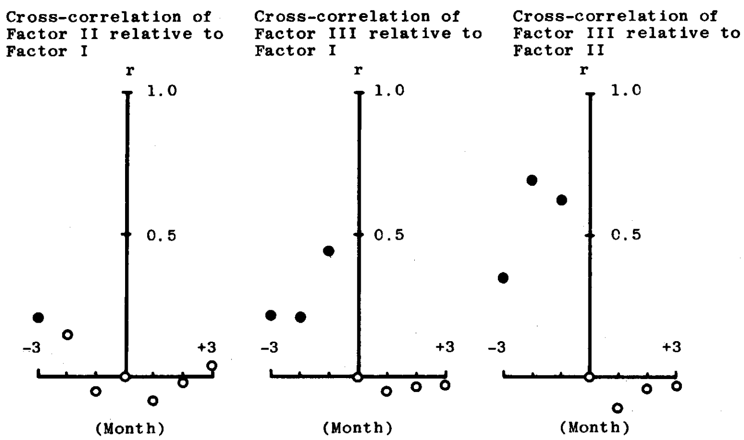

Fig. 9 Cross-correlation coefficients for lag values from −3 to +3 months between factor scores (cross-correlation coefficients at the 0.05 level are shown by solid points)

in terms of “interrelations” are not so scare as those for early modern times. The urban or regional system of the Meiji era (1868-1912), can ba partly elucidated by using newly discovered flow data (Morikawa, 1982). For example, factor analyses of data on interurban and inter-prefectural flows of bank drafts in the early and middle Meiji era indicate that Tokyo had already dominated Eastern Japan and Osaka Western Japan (Sugiura, 1978c, 1979, 1982). By the time the epidemic of Spanish influenza broke out, the zone from the Tokai to the Hokuriku districts approximately corresponded to the boundary between the spheres of influence of Tokyo and Osaka, while the sphere of influence of Tokyo had gradually encroached on that of Osaka (Yamagiwa, 1925a, 1925b). Judging from the fact that these spheres of influence of Japan’s two largest cities are coincident with the marked regionalization of Western Japan and Eastern Japan observed in connection with Factor I and Factor III, Spanish influenza certainly appears to have spread through the Western Japan urban or regional system and the Eastern Japan urban or regional system. On the other hand, Factor II is indicative of the tendency toward hierarchical diffusion. But it is unknown whether or not the Japanese urban or regional system was hierarchically structured enough at that time to allow a smooth hierarchical diffusion.

The following is a factor analysis of data on inter-prefectural railway commodity flows as of 1919, which facilitates investigation of the latter point. Unit areas consist of 45 prefectures—all except Kochi, where the national railway had not yet been opened. Fourteen factors with eigenvalues greater than 1.0 were extracted by R-mode factor analysis of the 45 (the number of origin prefectures) $\times$ 45 (the number of destination prefectures) data matrix. Table 4 shows factor naming based on both factor loadings greater than absolute value 0.5 (representing major destinations) and factor scores greater than absolute value 1.0 (representing major origins). Distributions of loadings and scores (Fig. 10) show that regions in Honshu on the Main Island were adjacently coexistent, while the peripheral regions of Hokkaido, Shikoku and Kyushu were relatively independent of others. The one exceptional case is Factor XII, identified as the inter-metropolitan region consisting of the Keihin metropolitan area of Eastern Japan and a part of the Keihanshin metropolitan area of Western Japan. Because of its small explained variance it is difficult to assert that intra-area flows of the Factor XII area were dominant compared with those of others, but it is of interest that a factor was extracted indicating an interconnection between metropolitan areas. Such connection may suggest that a Japanese urban or regional system was already hierarchically structured in terms of not only (population) “attributes” (Watanabe, 1968), but also “interrelations”. Thus it is inferred that Spanish influenza spread through the Eastern and Western Japan regional systems where adjacent regions overlapped and through a hierarchical regional system integrating the two systems.

Table 4-a Dominant factor loadings and factor scores of inter-prefectural railway commodity flow data

Factor	Prefecture	Factor loading	Factor score
	Saitama	0.9557	
	Tokyo	0.9385	3.9309
I	Gunma	0.9033	
	Ibaragi	0.8691	2.1343
6.8528	Tochigi	0.6955	1.6310
	Kanagawa	0.6789	1.8715
15.2%	Chiba	0.6646	
	Yamanashi	0.6612	
	Fukushima	0.6563	3.0882
	Nara	0.9100	
	Kyoto	0.8730	1.1577
II	Osaka	0.7811	5.3123
	Shiga	0.7268	
6.6105	Wakayama	0.7215	1.4185
	Mie	0.5345	
14.7%	Hyogo		1.9170
	(Yamaguchi		−1.0175)
III	Fukuoka	0.9172	5.9617
	Oita	0.8890	
3.4684	Kagoshima	0.8343	1.4878
	Kumamoto	0.8193	1.2934
7.7%	Miyazaki	0.5202	
	Gifu	0.8855	1.7351
IV	Aichi	0.8529	5.2543
	Mie	0.6490	1.3052
2.1631	Nagano		1.2272
	Shizuoka		1.2006
4.8%	(Tokushima		−1.0721)
V	Ishikawa	0.8826	3.6694
	Toyama	0.7154	3.4644
1.9990	Fukui	0.6692	3.0894
	(Nagano		−1.1233)
4.4%	(Tokushima		−1.0903)
VI			
1.8231	Ehime	0.9770	1.2034
	Kagawa	0.9735	6.2542
4.1%			
VII			
1.7167	Saga	0.9722	6.3052
	Nagasaki	0.9284	
3.8%			
VIII	Tottori	0.8353	4.0903
1.6180	Shimane	0.8177	3.7023
	Hyogo		2.7938
3.6%	(Tokushima		−1.0060)
IX	Yamaguchi	0.8091	4.8509
1.4184	Hiroshima	0.7787	2.7226
	Okayama		1.0973
3.2%	Hyogo		1.8677
X	Akita	0.8435	4.2073
	Aomori	0.7641	4.1143
1.3409	Yamagata		1.0645
	(Miyagi		−1.0313)
3.0%	(Tokushima		−1.0468)
XI	Niigata	0.8494	5.2758
	Nagano	0.6013	2.4720
1.2067	Toyama	0.5158	1.2730
	(Fukui		−1.6096)
2.7%	(Yamagata		−1.0601)
	Shizuoka	0.6072	3.4099
	Kanagawa	0.5767	2.6730
XII	Tokyo		1.8578
	Hyogo		1.2360
1.0800	Okayama		1.1237
	(Fukushima		−2.8321)
2.4%	(Yamagata		−1.3850)
	(Yamaguchi		−1.0359)
XIII	Iwate	0.7262	3.5639
	Miyagi	0.6757	3.8963
1.0246	Aomori		1.8892
	Fukushima		1.6817
2.3%	(Akita		−1.4349)
XIV			
1.0044	Hokkaido	0.7541	4.9455
	(Tokushima	−0.6464	−4.2403)
2.2%			

Note : $\frac{\text{Eigenvalue}}{\text{Percentage of variance}}$

Table 4-b Factor naming

Factor	Naming
I	The Kanto district
II	The Kinki district
III	The Eastern Kyushu district
IV	The Tokai district
V	The Hokuriku district
VI	The Northern Shikoku district
VII	The Western Kyushu district
VIII	The San'in district
IX	The San'yo district
X	The Tohoku-uranippon district
XI	The Shin'etsu district
XII	The inter-metropolitan region
XIII	The Tohoku-omotenippon district
XIV (positive)	The Hokkaido district
(negative)	Tokushima prefecture

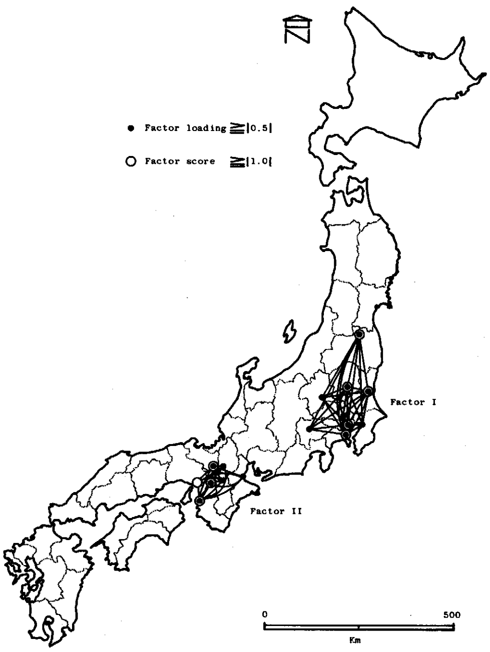

Fig. 10-a Regional system elucidated by factor analysis of inter-prefectural railway commodity flows, 1919

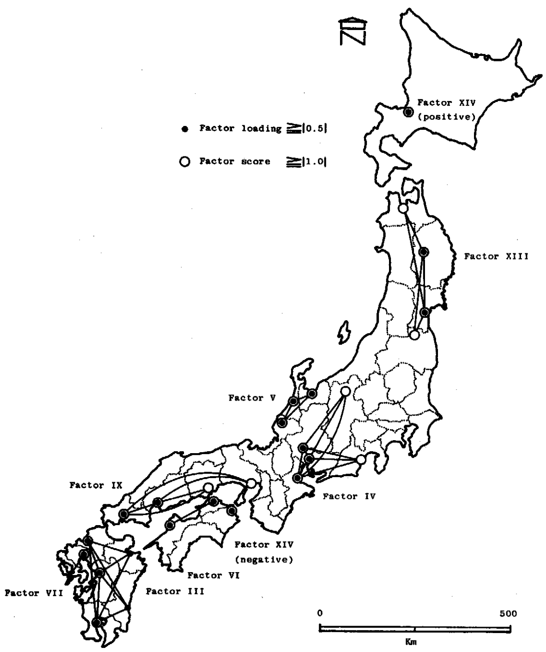

Fig. 10-b Same as Fig. 10-a

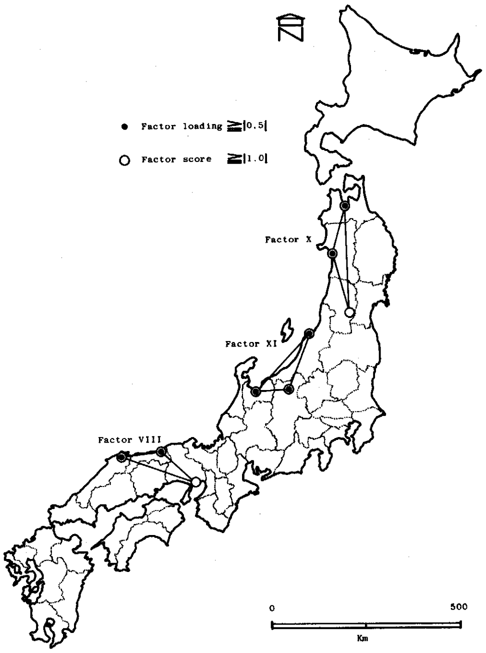

Fig. 10-c Same as Fig. 10-a

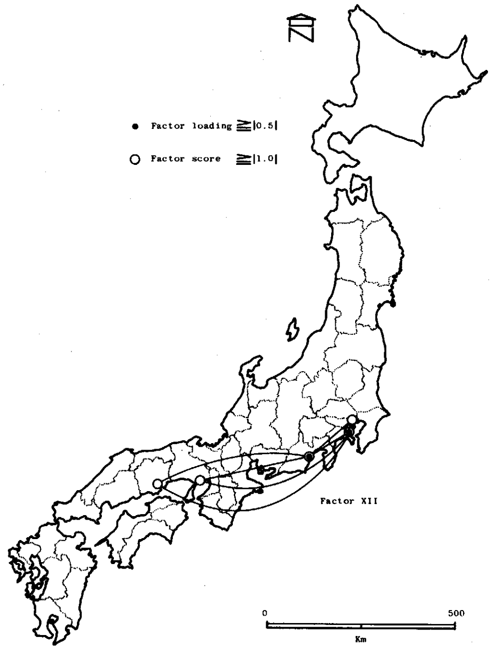

Fig. 10-d Same as Fig. 10-a

Conclusion

In terms of Hägerstrand's explanatory framework, this chapter has examined the diffusion of (cultural) epidemic phenomena, the process of which is generally dominated by the availability of information or by interactions, focusing upon correspondence to an urban or regional system as a diffusion channel. As a result, it turned out that such (cultural) epidemic phenomena as the Okagemairi and Spanish influenza had spread through the urban or regional system of that time. The perspective adopted in this chapter may have two implications for spatical diffusion research. The first is to give a more comprehensive meaning to factual descriptions such as "diffusion from larger to smaller cities" or "diffusion from urban to rural areas", which are ambiguous expressions used by urban sociologists (McVoy, 1940; Crain, 1966) and cultural geographers (Kniffen, 1951a, 1951b). The second is that attention to an urban system operating as a diffusion channel makes it possible to explain non-hierarchical diffusion from smaller to larger cities or diffusion between cities of identical order on the basis of the same explanatory framework: the origin points for introduction of innovations are varied, but they fundamentally spread through the same urban system.

4. Diffusion dependent upon adoption process

Introduction

Hägerstrand's explanatory framework stresses the communication process, but does not specify the decision-making process of adoption. Many innovations are not be adopted, however, as soon as people are simply informed of them: adoption rather involves a complicated decision-making process. For example, it will be essential for the case of an innovation whose adoption requires substantial capital to analyze the decision for adoption. There also appears to exist an innovation diffusion involving only decision-making process, and no communication process. This chapter investigates the mechanism of spatial diffusion of innovations where the decision-making process plays a larger role than the comunication process.

First, electricity supply companies will be taken as an example of innovation involving decision-making process. Locations of electricity supply companies depend upon market size in terms of customers for electricity, so that the market area may cover a certain areal range. This fact suggests that the diffusion process must be investigated with reference to not only the market size of a city itself with an electricity supply company but also its hinterland. Though such innovation diffusion has been considered in association with central place theory (Brown and Cox, 1971), there are no studies directly examining the relationship between innovation diffusion and market area division process. This is one of the reasons why electricity supply companies are considered here. The other reason is that electricity supply is judged to be an innovation suitable to a study of the market area division process because data are available on service areas. Market area division implies spatial division of a market area mainly restricted by distance. The study area is Fukushima prefecture, a representative study area for Japanese central place research (Watanabe, 1955).

Second, radio stations will be taken as an example of innovation involving no communication process. The opening of a radio station in each region results from a decision by Nippon Hoso Kyokai (NHK), the Japanese Broadcasting Corporation. Consequently, diffusion of radio stations, which corresponds to innovation diffusion as a result of centralized decision-making, as it will be termed later, should be examined in terms of the dynamic facility location principle (Brown, 1981). An operational definition of this principle corresponds to the object function of a facility location model. A number of alternative object functions have been proposed. They are ultimately grouped into either spatial efficiency type or spatial equity type (Hodgart, 1978). The former type aims at minimizing aggregate travel distance or mean travel distance. Since the equity cannot be uniquely defined, on the other hand, various criteria are used in constructing a spatial equity model for facility location. The minimax-distance criterion, minimizing the maximum travel distance to the nearest facility, is representative of the latter type.

The following example supports an analysis of radio station diffusion in terms of dynamic facility location to optimize efficiency: television stations, which are similar innovations, spread hierarchically in Japan at first (Inada, 1978; Higashi and Ugajin, 1979); since under the efficiency principle public facilities are preferentially located in larger cities with high population densities and high income levels (Morrill, 1974; Morrill and Symons, 1977), it is presumed that new facilities spread hierarchically under the efficiency principle. A comment is required on the application of the location-allocation model to this problem, however. This will be mentioned later.

Spatial diffusion of electricity supply companies in Fukushima prefecture

Outline of diffusion process

The Japanese electricity supply industry originally began in order to provide a new kind of lighting. It was one of a few new undertakings initiated by non-government people under circumstances where many government-managed industrial enterprises were inaugurated by national policy. Its purpose was to substitute electric light for obsolete paper-covered lamps, candles, oil lamps and gas lamps in order to improve public peace and order, prevent fires, reduce increasing petroleum imports, and promote the development of commerce and industry (Kotake, 1980, pp. 81-85). Electricity supply companies first used thermal power generation, but the rising price of coal and technological developments gradually induced them to adopt water power generation. Then improvement of power-transmission technology accelerated water power generation at places far distant from the markets or consuming centers, so that electricity generated by water power exceeded that by thermal power by the 1910's (Minami, 1965, p. 206). With the advent of water power generation a new market for electric motors was exploited to make efficient use of surplus electricity in the daytime, but electricity consumed for motors did not exceed that for light until the mid-1910's (Minami, 1965, p. 198). Shifting emphasis from supplying electric light to supplying electric power, electricity supply companies accomplished the so-called "Power Revolution" in which electric motors took the place of water turbines and steam engines or traditional generative power in manufacturing industry (Minami, 1976). The present study is concerned only with electricity supply companies providing electric light or both electric light and electricity.

The first electricity supply company in Fukushima prefecture started its business in Fukushima city in 1895, eight years after the first Japanese electricity supply company opened in Tokyo. By 1938, 55 electricity supply companies had opened, with the last openings in Niidate and Katsurao. Though all 55 companies were not simultaneously operating at any one time because of amalgamation, we can safely regard electricity supply companies as having formally opened in 55 cities, towns and villages. Forty-one companies, 75% of the total electricity supply companies, adopted water power generaion; eleven companies purchased electricity from other companies or other enterprises; three companies, in Taira, Onahama and Samegawa, adopted steam power generaton, gas generation or thermal power generation.

Fig. 11 shows the spatial diffusion of electricity supply companies at intervals of 10 years. Electricity supply companies had opened only in Fukushima city and Koriyama before 1899. By 1909 they were located in major towns of the Aizu area and of the northern and middle parts of the Nakadori area: Kitakata, Aizu-wakamatsu, Sukagawa, Nihonmatsu, Kawamata and Miharu, in that chronological order. They spread to Hamadori and Oku-aizu, areas far distant from Fukushima city, during the subsequent

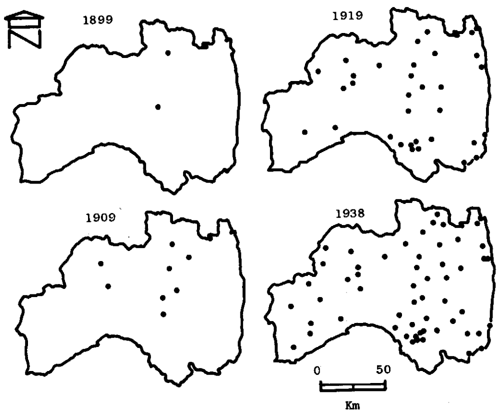

Fig. 11 Spatial diffusion process of electricity supply companies, Fukushima prefecture

10 years. They appear to have been uniformly located in 1938, except for Futaba sub-area of Hamadori and a boundary zone, in the Ohu mountains, between the Nakadori and the Aizu areas, where no electricity supply companies opened in the end. Application of nearest-neighbor measure (King, 1962) to the distributions of electricity supply companies as of 1909, 1919 and 1938 revealed that R-values were 0.7175, 1.0975 and 1.2383 (significant at the 0.01 level), respectively, suggesting that the distributions approached a uniform pattern. Judging from the fact that all the electricity supply companies were managed on a profit-making basis except for a one-man business in Hihashi and a union enterprise in Katsurao, the above result appears to indicate that electricity supply companies spread according to the market area division principle.

As shown in Fig. 12, a high correlation, $r=-0.759$ (significant at the 0.01 level), was obtained between opening year and log-transformed population of a city, town or village with an electricity supply company as of 1908. A more marked hierarchical diffusion process is observed by reexamining the matter by city-town-village categories (Fig. 13). That is, companies did not spread from larger to smaller towns simply according to population size order, but rather from cities to towns and towns to villages step-by-step. It would be necessary therefore to analyze diffuson process on the basis of city-town-village categories.

Diffusion of electricity supply companies in terms of market area division process

Aizu-wakamatsu and Fukushima city were the only cities in Fukushima prefecture in the Meiji era, 1868-1912. Fukushima city was the first adopter-city in the prefecture, but a diffusion process from cities to towns is not completely supported because two towns, Koriyama and Kitakata, had become adopters earlier than Aizu-wakamatsu. In this subsection the following statistical analyses are performed by using relevant variables, focusing upon 53 electricity supply companies located in towns and villages:

1) Step-wise forward discriminant analysis is applied to distinguish between 21 adopter-towns and 18 non-adopter-towns (Table 5).

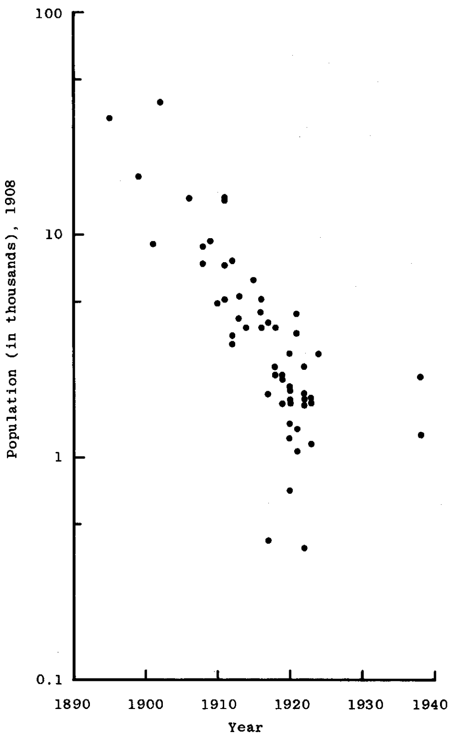

Fig. 12 Hierarchical diffusion of electricity supply companies, Fukushima prefecture

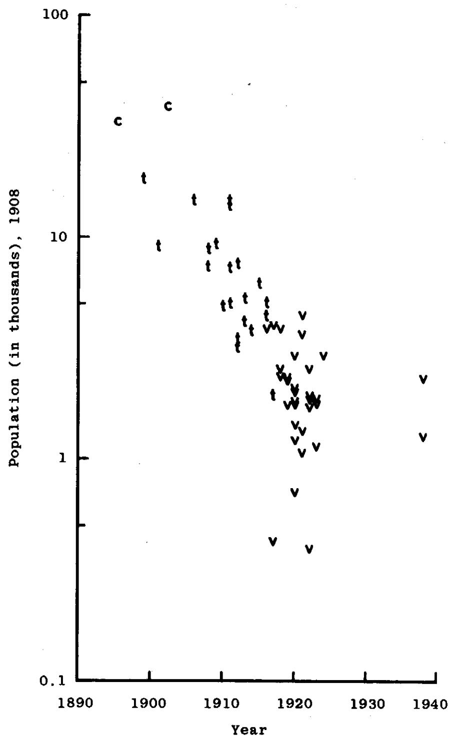

Fig. 13 Hierarchical diffusion of electricity supply companies in terms of city-town-village categories

Table 5-a Significant variables (F statistic is 2.0 or more) for discriminating between adopter-towns and non-adopter-towns

		Population	Number of textile manufacturing factories	Distance from Fukushima
Mean	Adopter	7,641.24	2.95	53.51
	Non-adopter	3,741.17	0.39	42.49
Order of entry		1	2	3
Standardized discriminant coefficient		0.5936	0.5660	0.5005

Tble 5-b Result of discrimination between adopter-towns and non-adopter-towns

		Predicted	
		Adopter	Non-adopter
Actual	Adopter	15 (71.4%)	6 (28.6%)
	Non-adopter	1 (5.6%)	17 (94.4%)

82.05% correctly classified

Table 6 Result of multiple regression analysis of opening year for adopter-towns (F statistic of significant variables is 2.0 or more)

	Population	Distance from Fukushima	Distance from the nearest adopter-city or -town
Correlation coefficient	−0.6353	0.4898	−0.3335
Order of entry	1	2	3
Standardized partial regression coefficient	−0.5665	0.4984	−0.2142
Multiple correlation coefficient	0.6853	0.8173	0.8389
Multiple determination coefficient	0.4697	0.6679	0.7038

2) Step-wise forward multiple regression analysis is performed for the opening years of 21 adopter-towns (Table 6).
3) Step-wise forward discriminant analysis is applied to distinguish between 186 villages within service areas of electricity supply companies located in cities and towns, and 194 villages outside their service areas as of 1917 (Table 7).
4) Step-wise forward discriminant analysis is applied to distinguish between 32 adopter-villages and 96 non-adopter-villages not adjacent to adopter-villages (Table 8).
5) Step-wise forward multiple regresion analysis is performed for the opening years of 32 adopter-villages (Table 9).

Results are shown in Tables 5—9. Detailed descriptions and comments on variables used here are presented in Sugiura (1978b). Based on these results, the diffusion of electricity supply companies is summarized as follows. Electricity supply companies, of which the first had opened in Fukushima city, generally spread in the order: city or regional center, town or local center, and village, according to the hierarchy effect. In particular, these time-lagged adoptions among city-town-village categories partly resulted from concentration of entrepreneurs on specific places as well as from market size (see Sugiura (1978b)).

The potential adopter-towns were those with large populations and where textile factories were located, indexing a certain level of demand for electric light and electricity. They were likely to be located outside the service area of the electricity

Table 7-a Significant variables (F statistic is 2.0 or more) for discriminating between villages within service area and villages outside service area in 1917

		Distance from the nearest adopter -city or -town	Number of workers in industry	Number of years between the opening of electricity supply company in the nearest adopter-city or -town and 1918	Distance from the nearest power station
Mean	Village within service area	7.20	283.58	10.40	8.0
	Village outside service area	10.44	177.32	8.06	10.91
Order of entry		1	2	3	4
Standardized discriminant coefficient		−0.4113	0.4658	0.3690	−0.3178

Table 7-b Result of discrimination between villages within service area and villages outside service area in 1917

		Predicted	
		Village within service area	Village outside service area
Actual	Village within service area	122 (65.6%)	64 (34.4%)
	Village outside service area	64 (33.0%)	130 (67.0%)

66.32% correctly classified

Table 8-a Significant variables (F statistic is 2.0 or more) for discriminating between adopter-villages and non-adopter-villages not adjacent to adopter-villages

		Potential hydraulic power place (1, otherwise 0)	Number of workers in industry	Population
Mean	Adopter	0.69	236.91	2,505.78
	Non-adopter	0.09	141.70	2,281.16
Order of entry		1	2	3
Standardized discriminant coefficient		0.9040	0.6047	−0.3595

Table 8-b Result of discrimination between adopter-villages and non-adopter-villages not adjacent to adopter-villages

		Predicted	
		Adopter	Non-adopter
Actual	Adopter	23 (71.9%)	9 (28.1%)
	Non-adopter	11 (11.5%)	85 (88.5%)

84.38% correctly classified

Table 9 Result of multiple regression analysis of opening year for adopter-villages (F statistic of significant variables is 2.0 or more)

	Number of workers in industry	Distance from Fukushima	Income tax per family
Correlation coefficient	−0.3548	−0.3034	−0.1682
Order of entry	1	2	3
Standardized partial regression coefficient	−0.3530	−0.4874	−0.3368
Multiple correlation coefficient	0.3548	0.4901	0.5742
Multiple determination coefficient	0.1259	0.2402	0.3297

Income tax per family is a surrogate variable representing income level.

supply company in Fukushima city. By this stage the market size of a city or town itself with an electricity supply company is a dominant factor in discriminating between adopters and non-adopters. For actual service areas in the opening year, in fact, 40 companies served many towns and villages with electricity, while 15 companies served only the city or town where they were located. Thus it was impossible for an electricity supply company to open unless it had several towns and villages within its own service area. For an adopter-city or -town, however, its own market size alone would meet a certain threshold in order for a company to open. Among towns fulfilling these conditions, the greater their population, the greater their information potential and the larger their potential service area, the earlier they became adopter-towns.

In this way electricity supply companies in cities and towns gradually extended their service areas to neighboring villages with some industrial activities within the limit of power transmission. In this regard electricity supply companies spread according to a significant market area division principle restricted by distance. In further executing market area division, electricity supply companies in cities and towns did not serve villages last, consciously excluding some small villages from their service areas. This very fact reveals the nature of profit-motivated innovation. In this stage the market area division principle based on opportunity distribution, such as population size, appears to have replaced the above-mentioned principle restricted by distance.

Even among villages not graced with electric light yet, however, those near hydroelectric sites and with industrial activities could potentially become adopter-villages. During the boom days of Wrold War I, then, among the villages fulfilling the above conditions, the further the villages were located outside the service area of Fukushima city's electricity supply company, and the more industrial activities and the higher income level they had, the earlier they bacame adopter-villages. Electricity supply companies, consequently, did not necessarily evaluate market size as a significant locational factor, though industrial activities were significant. This fact may reflect in a sense the market control strategy of electricity supply companies in cities and towns. There was no necessity to open in specific villages. This point is suggested by an unsuccessful discriminant analysis between adopter-villages and other villages not served by electricity supply companies in cities and towns, which is not reported here, and by the low explained variance of multiple regression analysis for adopter-villages shown in Table 9. Rather, the availability of hydraulic power was one of the factors determining the opening of electricity supply companies. They could have opened in any village near a hydroelectric site. This very condition facilitated the opening of electricity supply companies with semipublic aim of raising village living standards and culture levels (Sugiura, 1978b). It should be noted, however, that the fact that income indexing the latent demand has contributed to explaining the opening year shows not the public but semipublic nature of electricity supply companies.

It turned out that the hierarchy effect observed in the diffusion of profit-motivated innovation involves the market area division process, though the focus of consideration (that is, to analyze the expansion of service areas), was limited to one year. In addition, this section has shed some light on entrepreneurs' market preference, because the openings of electricity supply companies in villages had to be comprehended with reference to those in cities and towns. Hence it will be necessary to elucidate the hierarchy effect further, not only with reference to the urban hierarchy but also with reference to entrepreneur behavior.

Spatial diffusion of NHK radio stations

Outline of diffusion process

In 1925 three corporations separately opened the first Japanese radio stations, with capacities of 1.5 kw, in Tokyo on March 22, in Osaka on June 1 and in Nagoya on July 15. Acting on the Communication Ministry's policy that the broadcasting industry should be organized in a national unity type, Nippon Hoso Kyokai (NHK), or the Japanese Broadcasting Corporation, was started by the amalgamation of the three broadcasting corporations (Nippon Hoso Kyokai, 1977). NHK's service network extension project was first to network the country—that is, to improve the three stations' capacities to 10 kw during the period 1926 to 1930, second to install stations with capacities of 10 kw in Hiroshima, Kumamoto, Sendai, Sapporo and Nagano and studios in Kyoto, Fukuoka and Aomori. But this project was sharply scaled down on account of the 1927 economic panic, so that all planned radio stations construction was postponed except for four stations with capacities of 10 kw which opened in Sapporo, Sendai, Kumamoto and Hiroshima in

1928, and one with capacity of 3 kw in Kanazawa which opened in 1930. With the openings of these stations, NHK reorganized itself into a seven-branch system with bases in Kanto, Kansai, Tokai, Hokkaido, Tohoku, Chugoku and Kyushu.

The realization of the first expansion project, whereby NHK's radio service could cover about half the households all over the country, however, was far from attaining the initial goal of enabling people everywhere to receive radio waves by means of crystal wireless sets. This situation resulted from two unexpected factors: 10 kw stations covered a narrower area than expected, and radio waves were considerably interrupted by obstructions such as local terrain. Thus a second expansion project was drawn up. Its essential features were as follows: based on the prospect that power stations as large as 10 kw might no longer be needed in terms of terrain conditions in Japan, many small power stations should be located in densely populated urban or plains areas in order to extend higher electric intensity (Nippon Hoso Kyokai Hoso-shi Henshu-shitsu, 1965, p. 261). The second expansion project, which had begun with the opening of Fukushima station in 1930, realized the openings of the total of 17 stations, one 1 kw station, twelve 0.5 kw stations and four 0.3 kw stations. Thus the national broadcast network had been completed to relay among 25 stations: the northernmost station is located in Asahikawa on Hokkaido and the southernmost station in Kumamoto on Kyushu.

But even the second expansion project did not yet attain the goal of covering the country with appropriate radio field intensity. In the course of enforcement of the second expansion project, a heated movement developed to open stations in regional centers where radio field intensity was weak. A third expansion project was therefore further drawn up, in continuation of the second: 0.05 or 0.1 kw stations would be located in 20 or so larger cities with high population densities, ranking next to 25 adopter-cities, taking into account 1) the diffusion level of radio sets, 2) regional demand for radio stations, 3) difficulty of receiving radio waves and 4) quantity of materials for local broadcasting. As a result, a total of 18 stations, that is, twelve 0.5 kw stations, three 0.3 kw stations and three 0.1 kw stations, opened during the period between 1935 and 1941, when the Pacific War broke out. The first station was in Kagoshima and the last in Oita (Nippon Hoso Kyokai Hoso-shi Henshu-shitsu, 1965, pp. 327—328). Owing to a building materials shortage, Fukushima and six other stations were postponed until 1941, though their installation had been mandated in 1938. After the Pacific War broke out, the broadcasting industry was used as a tool to conduct the war, and many stations as small as 0.05 kw were installed in response to it. Some of these were raised to the status of regular stations after the war. Their nature and standards were, however, quite different from those installed before 1941. Such being the case, the present study considers only the 43 stations opening before the outbreak of the Pacific War.

Diffusion of NHK radio stations in terms of facility location process

Fig. 14 shows the diffusion process of radio stations, related to adopter-cities' populations. There is a correlation, $r=-0.757$ (significant at the 0.01 level) between opening year and log-transformed population as of 1935, suggesting a hierarchical diffusion pattern. Detailed examination of Fig. 14 reveals that radio stations did not sequentially spread, but rather spread step-by-step according to NHK's expansion projects as described above. In the present study, then, the period concerned is divided as

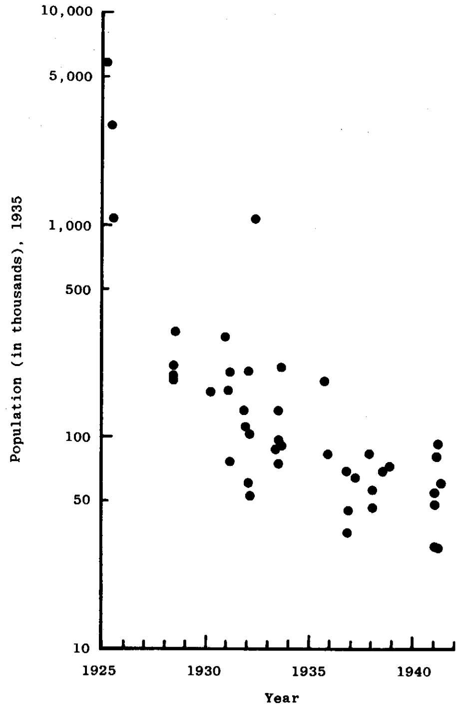

Fig. 14 Hierarchical diffusion of radio stations

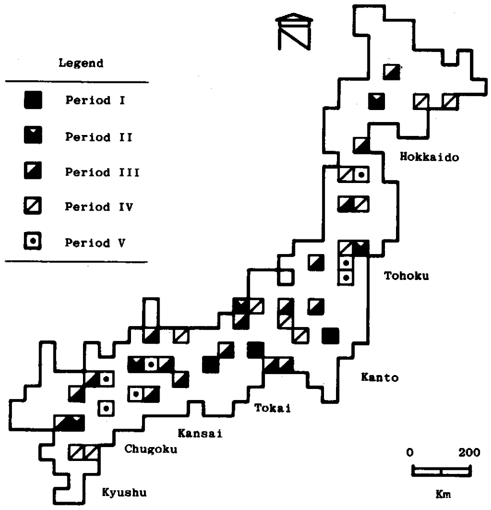

Fig. 15 Opening period of radio stations

follows:

Period I: Three broadcasting corporations in Tokyo, Osaka and Nagoya separately opened in 1925.

Period II: Sapporo, Sendai, Hiroshima, Kumamoto and Kanazawa stations opened according to NHK's first expansion project in the period 1928—1930.

Period III: Seventeen stations opened according to NHK's second expansion project in the period 1930—1933.

Period IV: Eleven stations opened according to NHK's third expansion project (first half) in the period 1935—1938.

Period V: Seven stations opened according to NHK's third expansion project (latter half) in 1941.

Spatial patterns of radio stations by periods will be considered in this sub-section (Fig. 15). Diffusion of radio stations is simulated using Törnqvist's algorithm, one of the dynamic facility location-allocation model simultaneously optimizing both the locations of a given number of facilities and the assignment of flows from demand points to facilities to minimize the total travel distance. In the present study distance is construed not as the travel distance to a facility, but as the radio wave travelling distance. In other words, to maximize efficiency in this context means minimizing the total radio wave travelling distance to listeners. Törnqvist's algorithm is shown in Fig. 16 (see also

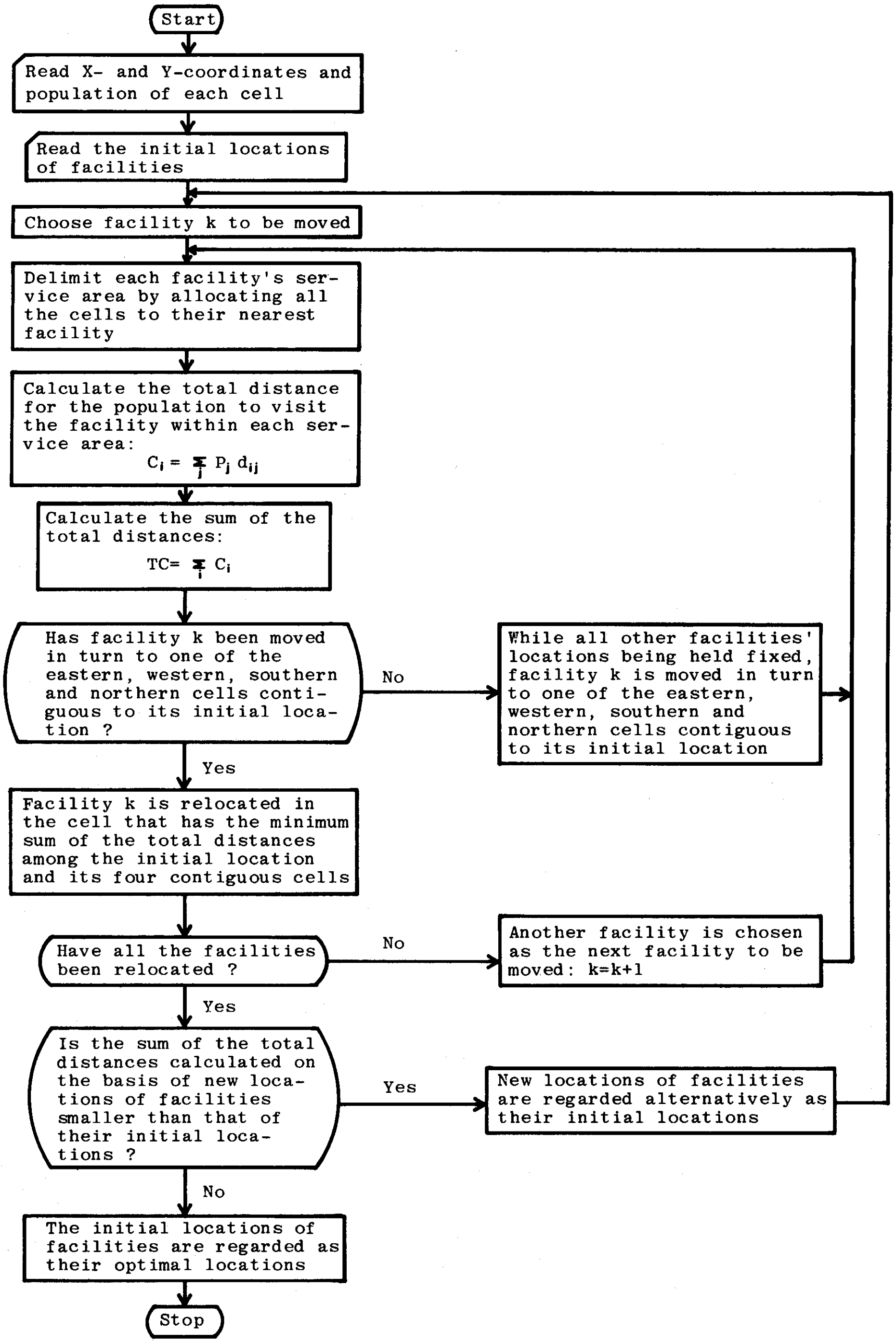

Fig. 16 Törnqvist's algorithm

Sugiura (1983a) and Törnqvist (1971)).

In searching for optimal solutions in each period, the locations of three stations in Period I, Tokyo, Osaka and Nagoya, are always given in the model. Since they were separately established originally, their openings were qualified differently from subsequent openings by NHK as a single corporation. Fig. 17 shows the optimal locations of five stations in Period II, as simulated by Törnqvist's model. In this case optimal solutions are sought in two ways: after fixing the locations of the Tokyo, Osaka and Nagoya stations, OPTIMAL-I locates five radio stations over the country; OPTIMAL-II locates one radio station within each service area of the branches of Hokkaido, Tohoku, Tokai (where the Nagoya station is assumed as fixed), Chugoku and Kyushu. Only the simulated location for the Hokkaido branch was completely identical to the actual one in both solutions. Stations in the branches of Tohoku, Chugoku and Kyushu are, however, theoretically located in cells adjacent to those occupied by Sendai, Hiroshima and Kumamoto respectively. In the case of the Tokai branch, while OPTIMAL-I theoretically located a station in the cell occupied by Nagano and served by the Kanto branch, OPTIMAL-II theoretically located a station in the cell adjacent to one occupied by Kanazawa.

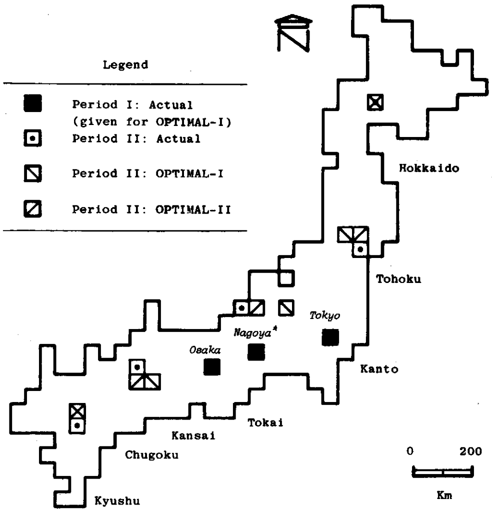

Fig. 17 Optimal locations of radio stations in Period II (Nagoya radio station is also given for OPTIMAL-II)

Judging from both solutions, we might safely say that these five cities, Sapporo, Sendai, Hiroshima, Kumamoto and Kanazawa, were appropriately chosen as the adopter-cities in terms of maximizing efficiency. Comparing the OPTIMAL-I solution with the OPTIMAL-II solution, we notice that the latter best fits the actual locational pattern in the branches of Tohoku, Tokai and Chugoku, except for the Hokkaido and

Kyushu branches where both solutions were identical. This fact implies that the range of a service area influences the subsequent openings to great extent. Therefore simulations for Periods III to V will be performed for each branch's service area.

Fig. 18 shows the optimal solution for Periods III to V, assuming the 8 radio station openings in Periods I to II as fixed. The solution is not so identical to the actual as expected. Then characteristics of adopter-cities in Periods III to V, which had not been located according to a simple efficiency principle, were specifically reconsidered to gain further insight by performing the following analyses:

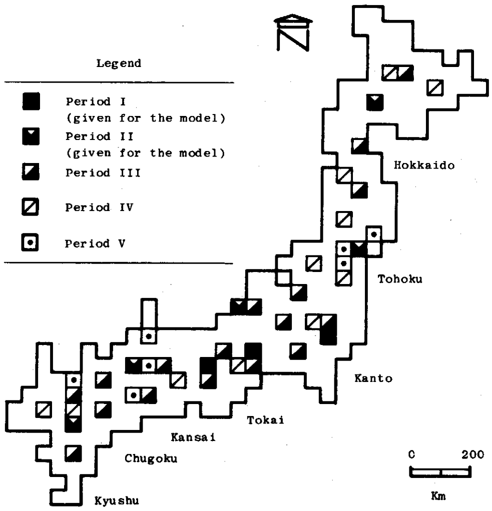

Fig. 18 Optimal locations of radio stations in Periods III-V

1) Assuming all the cities as of 1935 to be potential adopter-cities, Hayashi's quantification model II or a discriminant analysis for categorical data is applied to distinguish between adopter-cities and non-adopter-cities (Table 10).
2) Hayashi's quantification model I or a multiple regression analysis for categorical data is applied to regress relevant variables on opening year for 35 adopter-cities in Periods III to V (Table 11).

Taking into account the results, detailed interpretation of which is described in Sugiura (1983a), Törnqvist's model was reapplied to the cells with radio stations actually located in Periods III to V. The adjusted optimal solution relatively resembles the actual locational pattern except for the Kyushu and Tohoku branches (Fig. 19). Provided that the optimal efficiency principle was applied to such potential adopter-cites as regional centers or prefectural seats located relatively distant from larger cities but not favorable to radio waves reception, the solution taken here may make the diffusion process of radio stations interpretable in terms of a dynamic facility location.

This section thus reveals that the following hierarchical diffusion of radio stations might, to some extent, result from an application of the optimal efficiency principle: the

Table 10-a Hayashi's quantification model II analysis of potential adopter-cities

Variable	Category	Number of obser-vations	Category weight	Range	Partial correlation coefficient
Population (in thousands)	−50	39	0.047		
	50—100	52	0.002		
	100—	26	−0.074		
				0.121	0.047
Population (in thousands) within a radius of 75—100 km of the city concerned	−1,000	7	−0.554		
	1,000—2,000	23	−0.062		
	2,000—3,000	20	−0.466		
	3,000—4,000	20	−0.036		
	4,000—5,000	16	0.136		
	5,000—	31	0.424		
				0.979	0.319
Prefecutral seat	No	79	0.333		
	Yes	38	−0.692		
				1.024	0.436
Distance from the nearest larger city	−50km	84	0.287		
	50—100	19	−0.296		
	100—	14	−1.318		
				1.605	0.443
Topographically weighted distance from the nearest adopter-city in Periods I to II	−100km and non-existence of intervening mountains	53	0.014		
	−100 and existence of intervening mountains	15	0.227		
	100km−	49	−0.085		
				0.312	0.108

Correlation ratio=0.557

Table 10-b Result of of discrimination between adopter-cities and non-adopter-cities based on Hayashi's quantification model II

		Predicted	
		Adopter	Non-adopter
Actual	Adopter	28 (82.4%)	6 (17.6%)
	Non-adopter	9 (10.8%)	74 (89.2%)

87.2% correctly classified

first Japanese radio stations in the three largest cities of Tokyo, Osaka and Nagoya started their services in Period I; those of such (semi-) regional capital cities as Sapporo, Sendai, Kanazawa, Hiroshima and Kumamoto, in Period II; and those of prefectural seats or other regional centers, in Periods III to V. If there remains an unsolved problem, it is the propriety of an application of an ordinary facility location model, assuming that

Table 11 Hayashi's quantification model I analysis of opening year

Variable	Category	Number of obser-vations	Category weight	Range	Partial correlation coefficient
Population (in thousands)	−50	6	29.345	48.188	0.506
	50—100	18	1.734		
	100—	11	−18.843		
Population (in thousands) within a radius of 75—100km of the city concerned	−1,000	4	−3.002	36.994	0.501
	1,000—2,000	9	13.559		
	2,000—3,000	12	10.368		
	3,000—	10	−23.435		
Prefectural seat	No	11	15.053	21.952	0.367
	Yes	24	−6.899		
Distance from the nearest adopter-city	−50km	12	10.100	52.556	0.630
	50—100	11	22.151		
	100—	12	−30.405		
Topographically weighted distance from the nearest adopter-city in Periods I to II	−100km and non-existence of intervening mountains	6	3.249	4.974	0.088
	−100km and existence of intervening mountains	6	3.273		
	100km−	23	−1.701		

Multiple correlation coefficient=0.840

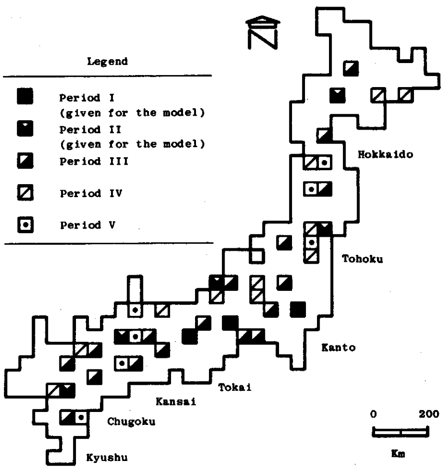

Fig. 19 Adjusted optimal locations of radio stations in Periods III-V

we alternatively interpret the travel distance to a facility as the radio wave travelling distance. If this application is accepted, then the solutions obtained here should be compared with the optimal equity model solution in order to clearly show the intervention of the optimal efficiency principle.

Conclusion

The analysis in this chapter has been performed under the assumption that electricity supply companies and NHK radio stations would open on the basis of the market area division and the facility location criteria, respectively. It turned out that the hierarchical diffusion patterns observed in both examples could appear when entrepreneurs or propagators of innovation act according to these decision-making criteria. This fact indicates that Hägerstrand's explanatory framework ought to be extended or revised, as it did not originally take this aspect into account. Nevertheless, the explanation in this chapter has been consistently normative in nature, and the present study is not directly concerned with the decision-making process itself from cognition, learning and preference to adoption. In order to approach it, an analysis would be required to operationalize these psychological constructs as well as collecting relevant data. Until now, however, behavioral geography has not presented a persuasive explanatory and/or analytical framework at all; in addition, there is some criticism on the behavioral approach (Bunting and Guelke, 1979; Sugiura, 1983b). A normative explanation has been adopted in this chapter, therefore, rather than the behavioral approach which is not appreciated yet. The author just takes the view that the normative explanatory framework should be well developed first, as suggested by Harvey (1969b), before geography tackles such intricate internal human problems as decision-making. This view will be taken in the next chapter, too.

5. Discussion: toward a new explanatory framework

Introduction

The preceding discussion has pointed up the isomorphism observed in various spreading phenomena by taking innovation in a broad sense. As illustrated by the examples of electricity supply companies and NHK radio stations, however, a seemingly identical hierarchical diffusion pattern could be produced by quite different diffusion mechanisms. The same will be true of a spatially contagious diffusion pattern. These problems call for articulating the meanings of the neighborhood and hierarchy effects as empirical regularities, which have been traditionally accounted for mainly based on communication process. Thus it is necessary to reexamine the diffusion mechanism in order to slove them. This chapter begins by investigating the fragility of Hägerstrand's explanatory framework, taking notice of elements constituting spatial diffusion of innovation: 1) innovation; 2) sender of information about innovation; 3) receiver of information about innovation; 4) communication network connecting sender with receiver.

Appearance of an innovation, above all, depends upon the existence of persons or organizations expecting new contrivances. Accordingly the first problem is to confirm the adoption unit of the innovation concerned. Together with the subsequent identification of potential adopters, this confirmation is important in that it implies a limit within which innovation can spread. How innovation spreads within the limit depends upon a communication network which is shaped by adopters as senders of information and non-adopters as receivers of information. The final adoption time of an innovation by individuals or individual organizations will be determined by the individual differences in economic, social and psychological thresholds for innovation adoption. This is directly related to the adoption process problem. Individual differences, however, seem to be not always constant, but to be constrained by the nature of the innovation concerned as well.

It has already been pointed out that Hägerstrand's explanatory framework needs to be refined to include the adoption process (Sugiura, 1976). The above discussion, however, will suggest that the adoption unit problem and the nature of innovation ought to be appropriately considered in a new explanatory framework, too. Before tackling the adoption process problem, which regrettably is not dealt with in the present study on account of its difficult nature, this chapter first classifies the innovation with reference to adoption unit, and second examines an explanatory framework for comprehending the corresponding diffusion mechanisms. This attempt is to keep in step with—and in fact is much indebted to—Brown's work (1975, 1981) aiming at shifting the research paradigm from the communication-biased perspective to the market and infrastructure perspective.

A new explanatory framework for spatial diffusion of innovation

On types of innovation

Following Pedersen (1970), innovation is categorized into two types. The first type is termed household innovation. Examples are new techniques or consumer goods accepted by households or individuals, membership in associations or cooperatives, and so on. In contrast, innovations adopted by enterprises, new policies adopted by municipalities and new types of public facility are termed entrepreneurial innovation. Entrepreneurial innovation is characterized by direct consequences for people other than the adopter or the founder. The present study has implicitly analyzed diffusions of the Okagemairi and Spanish influenza in a context similar to household innovation, and diffusions of electricity supply companies and radio stations explicitly in the context of entrepreneurial innovation. Entrepreneurial innovation has been conveniently regarded as being adopted by city or town. The present study will follow this view, too. In addition, many household innovations have corresponding entrepreneurial innovations as will be mentioned later. For example, installation of running water in a dwelling requires the establishment of a water supply system in the community, and the opening of a radio station is indispensable to the spread of radio sets. The difference between these two types of innovation consists in the following two points: 1) the entrepreneurial innovation often involves a higher risk economically, socially or politically than the equivalent household innovation; 2) while for the household innovation, each new adoption tends to increase the spread of diffusion, entrepreneurial innovation is competitive in the sense that its first adoption in a city of a size about the threshold level for the innovation may block its further introduction (Pedersen, 1970).

A diffusion mchanism for entrepreneurial innovation

Sub-classification of innovation types and their corresponding diffusion mechanisms are described below. First, on the basis of decision-making structure, entrepreneurial innovation is classified broadly into two categories: innovation with centralized decision-making and innovation with decentralized decision-making. The former is the case when a single propagator distributes innovations in each district, as illustrated by the location of NHK's radio stations. The latter is when many independently organized entities establish innovations in each district, as illustrated by the openings of electricity supply companies. If we take into account whether the innovation is profit-motivated or not, entrepreneurial innovation is classified into four types. The electricity supply company belongs to the category of profit-motivated innovation and NHK's radio station to the category of non-profit-motivated innovation. In Japan, generally, the diffusion patterns of profit-motivated innovations differed from those of non-profit-motivated innovations during the Meiji and Taisho eras (Sugiura, 1978c).

In the case of profit-motivated innovation with centralized decision-making structure, it is posited that locations of innovation are successively chosen in the order of estimated profitability, after alternative locations are ranked on the basis of the profitability criterion within a given budget. Brown has devised a gaming simulation model called PROMAR, to gain further insight into the diffusion process of innovation in the real world (Brown *et al.*, 1977; Craig and Brown, 1978, 1980). But no relevant model has yet been developed to directly analyze the diffusion process in real geographic space. In the case of non-profit-motivated innovation with centralized decision-making structure, a linear programming model could be used, and such a model has been applied to the location-allocation problem of public facilities, optimizing service by minimizing the total travel distance or the maximum travel distance to the nearest facility (Holmes *et al.*, 1972; Brown *et al.*, 1974). We can see here a close relationship between spatial diffusion research and location-allocation research of facilities. Diffusion of NHK's radio stations has been considered from this perspective. In any case, diffusion of innovation with centralized decision-making structure must be approached in terms of the dynamic facility location, in that its propagator is single.

In the case of profit-motivated innovation with decentralized decision-making structure, on the other hand, profitability will operate only as a threshold for innovation establishment. It is posited that the time when an innovation is established in the set of locations where the profitability threshold condition will be met will depend upon exposure to existing entities. This view is certainly supported by the case of electricity supply companies in Fukushima prefecture, at least as they spread in cities and towns. Pedersen (1970, 1975) has presented the following explanatory framework for this type of innovation diffusion, enumerating five relevant components: 1) exposure to the innovation; 2) threshold condition related to economic and technical feasibility of innovation; 3) general willingness to adopt innovations; 4) national or local government's institution and policy of controlling or promoting innovation adoption; and 5) the presence of a potential entrepreneur in the city. If there is at least one pioneering entrepreneur ready to adopt an innovation in cities of size greater than the threshold level, where institution or policy makes its adoption feasible, the innovation will be adopted in the city concerned when it has received sufficient information about the innovation from adopter-cities. Of these components, the amount of information flow from adopter-cities to non-adopter-cities could be approximated by a gravity model as used in Chapter 3. The denominator of the gravity model equation may represent the neighborhood effect, and the numerator the hierarchy effect. We can also see here a close relationship between spatial diffusion research and spatial interaction research.

Next, since the frequency of entrepreneurs is very small and the stochastic element is likely to be inherent to a greater extent than other conditions, the Poisson distribution gives the probability S that at least one entrepreneur is found in a city of a given population P, provided that potential entrepreneurs are distributed randomly throughout the population at a small frequency q (Pedersen, 1970):

$$S=1-f_0=1-e^{-\lambda}\frac{\lambda^0}{0!}=1-e^{-\lambda}=1-e^{-pq}$$

where λ is the mean number of entrepreneurs in cities of population size P and f_0 is the probability that no entrepreneurs are found in a city.

Brown (1975, 1981) indicates that Pedersen's explanatory framework would be applicable to the non-profit-motivated context as well, if the threshold condition is defined by a non-economic criterion instead of an economic one. Finally, if we construe that the above-mentioned institution and policy relevant factors will suggest the necessity of taking into account the presence of a coordinating or central propagator assisting or controlling individual establishment of an innovation in each place, then entrepreneurial innovation may be classified into six types (see Fig. 20).

A diffusion mechanism for household innovation

In most cases, household innovation diffusion depends upon the establishment of diffusion agencies constraining each household's or individual's access to it. If its propagator is single and distribites a household innovation through already existing diffusion agencies such as supermarkets, special diffusion agencies will be dispensable. But if diffusion agencies are indispensable, their establishment itself could be conceived as the allocation of innovation with centralized decision-making structure in the places concerned. If the case is such that household innovations are distributed by many independent entities newly located in each place, these entities appear to be diffusion agencies themselves. Accordingly, these establishments are nothing less than entrepreneurial innovation establishments in a decentralized decision-making setting. It is necessary to regard diffusion of entrepreneurial and household innovations as a sequence phenomenon.

It is posited that a diffusion agency generally creates an infrastructure for information and innovation provision within its territory as a part of its propagating approach to potential adopters, while utilizing the already existing diffusion-promotive infrastructure such as transportation, electricity and water systems. Though utilization and creation of an infrastructure are associated with diffusion agency's strategy, potential adopters' access to information and to innovation more or less depends upon the location of the diffusion agency. As will be mentioned in the next section, for example, the locations of NHK's Nagoya branch and of radio dealers partly determined the distribution of radio subscribers in Nagoya and its environs (Sugiura, 1981a). Thus we can classify household innovations into infrastructure-constrained and infrastructure-independent innovations: in the former, potential adopters' or diffusion agency's costs in utilizing the infrastructure are inversely related to the distance to specific places such as diffusion agencies or urban centers; the latter is innovation independent of infrastructure.

In this way the diffusion pattern of household innovation is roughly shaped with reference to the diffusion agency. As suggested by sociologists (Rogers, 1962), information communicated by existing adopters seems to be critical in the final decision to adopt an innovation. In fact, Hägestrand's work presented an explanatory framework for this stage. In any case, analysis of the adoption decision-making process for a household innovation should not be undertaken until the analyses of the stages referred to in the preceding paragraphs are terminated.

There are few studies using psychological constructs relevant to the decision-making process in spatial diffusion research. Exceptional cases are DeTemple (1971; see also Sugiura (1981b)) and Brown (1980) using Rushton's (1969a, 1969b) revealed space preference concept and attitude measurement method, respectively. Thus an unsolved and intricate problem still remains: creating an analytical model of the adoption decision-making process which will complement Hägerstrand's model as an information spread model. This may depend a great deal upon the development of behavioral geography extensively resorting to psychological constructs.

An evaluation

The explanatory framework for spatial diffusion of innovation described in this chapter was presented for the purpose of comprehensively explaning the whole diffusion process through the analysis of behaviors associated with innovation supply and demand. One advantage of this explanatory framework is that it appears to provide a solution to the controversy between economists and sociologists on hybrid corn diffusion. While economists (Griliches, 1957, 1958, 1960a, 1960b, 1962) who made much account of economic rationality insisted that the diffusion of hybrid corns was determined by both seed producers' market selection (aiming at securing profit) and adoption of hybrids by farmers expecting increases in returns, sociologists (Brandner and Straus, 1959; Havens and Rogers, 1961; Rogers and Havens, 1962; Babcock, 1962) instead insisted on the importance of interaction among farmers, if only to communicate the fact of profitability. If we examine this controversy with reference to the above-mentioned explanatory framework, economists seem to emphasize the innovation supply side and sociologists, the demand side. The explanatory framework presented here, therefore, enables us to give a systematic interpretation of the complicated matter of hybrid corn diffusion.

Fig. 20 shows the relationship between entrepreneurial and household innovations described in this chapter. Table 12 also epitomizes the position of some empirical studies in spatial diffusion research on innovation, to illustrate the correspondence between innovation types and three dominant spatial diffusion patterns. This table was drawn up by selecting arbitrarily from the literature near at hand one representative study

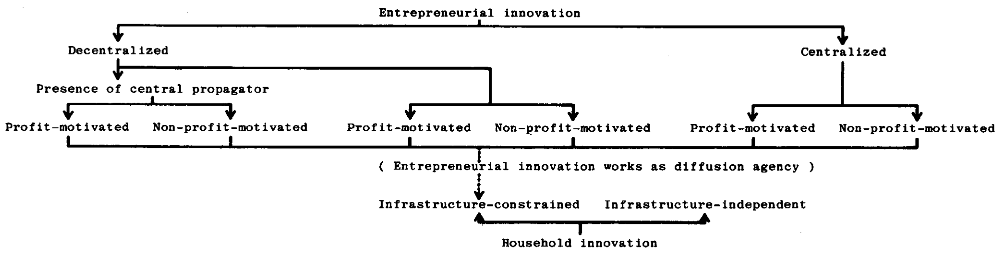

Fig. 20 Relationship between entrepreneurial and household innovations

reporting each of the three diffusion patterns by figures or through results of statistical analysis. Blanks in Table 12 are entirely attributable to lack of studies. Table 12 shows no tendency for specific types of innovation to concentrate in specific spatial diffusion patterns. Though analysis was not attempted here, the occurrence frequency of each type of innovation in the three spatial diffusion patterns could be calculated by locating the empirical studies in any portion of Table 12. If we take into account the fact that even the same type of innovation could spread in different ways in geographic space by the action of the relevant factors already pointed out, Table 12 suggests that an analytical model should be constructed, operationalizing relevant factors on the basis of the explanatory framework presented here.

Spatial analysis based on the new explanatory framework

To sum up, the new explanatory framework has resulted in clarifying the "role charge" of Hägerstrand's explanatory framework. Faithfully following Hägerstrand, recently the Bristol school (Cliff *et al.*, 1981) has studied epidemic diffusion. Attaching importance to the concept of (tempo-)spatial autocorrelation, they undertook spatial analysis of infectious disease diffusion. Virtually all phenomena of interest to geographers are primarily filled with spatial autocorrelation, which reminds us of the first law of geography as Tobler (1970, p. 236) described it: "Everything is related to everything else, but near things are more related than distant things". Cliff and Ord (1973), considering spatial autocorrelation as a geography's leading concept, rather ambitiously attempted to build a highly universal (tempo-)spatial model explicitly including spatial autocorrelation itself, although spatial autocorrelation has widely been negatively treated as a noise in applying statistical methods in geography. They intend to apply their type model not only to infectious disease diffusion, but also to socio-human phenomena at large (Cliff and Ord, 1981).

In terms of space views, their study connotes the separatist view that spatial phenomena are dealt with in abstraction from social process. Spatial separatism holds that it is possible to identify, separate and evaluate the effects of the spatial, either as an independent phenomenon or as a property of events examined through spatial analyses (Sack, 1974). This view really pertains to the absolute view of space, insisting that any statement on space cannot be reduced to other statements referring to neither space nor spatial attributes (Hinckfuss, 1975).

Table 12 Positioning of some studies in terms of both type of innovation and spatial diffusion pattern

Type of innovation		Spatially contagious diffusion pattern	Hierarchical diffusion pattern	Random diffusion pattern
Entrepre-neurial	Centralized decision-making structure : profit-motivated	Friendly ice cream shop (Meyer and Brown, 1979)		
	Centralized decision-making structure : non-profit-motivated	Native administration (Riddell, 1970)	Radio station (Sugiura, 1983a)	Postal agency (Witthuhn, 1968)
	Decentralized decision-making structure : profit-motivated (without a central propagator)	Industries (Abumere, 1979)	Electricity supply company (Sugiura, 1978b)	
	Decentralized decision-making structure : profit-motivated (with a central propagator)			Credit card services by banks (Brown and Malecki, 1977)
	Decentralized decision-making structure : non-profit-motivated (without a central propagator)		Rotary Club (Huang and Gould, 1974)	Fluoridation (Agnew *et al.*, 1978)
	Decentralized decision-making structure : non-ptofit-motivated (with a central propagator)	Cooperative movement (Brown *et al.*, 1978)	Urban renewal (Agnew *et al.*, 1978)	Montessori education (Meyer, 1975)
Household	Infrastructure-constrained	Artificial insemination of cattle (Hanham and Brown, 1976)	Television set (Berry, 1972)	Hybrid maize (Garst, 1974)
	Intrastructure-independent	Grazing improvement subsidy (Hägerstrand, 1953)		Postal checking account (Hägerstrand, 1953)

The antipodal view of the absolutist is the relational view of space, or that of the relationalist. The relationalist insists that any statement on space can be reduced to statements describing the relationships between other substances or events. For example, consider the statement that empty space is transparent. The relationalist might say that to state that space is transparent is just to state that if there is nothing in the path of a light ray the light proceeds unimpeded. This reduction does seem to be equivalent to the original statement that empty space is transparent, but it no longer seems to refer to some entity called "space" (Hinckfuss, 1975, p. 5). The question at issue is not concerned with the space concept which geography will depend upon: absolute space independent of material objects—that is, space as a container of all material objects, or relative space —that is, space interacting with material objects. Rather, it is concerned with language selection: what kind of language should be used for explanation in geography. In other words, the problem is choosing between space-time language referring to the position occupied by an object and substance language referring to the properties which the object manifests (Harvey, 1969a).

In terms of these two space views, then, let us reconsider Hägerstrand's model and the explanatory framework shown in this chapter. As Hägerstrand himself confessed, his model is undoubtedly physicalist in nature (Buttimer, 1983). But the distance appearing in his model is only a surrogate variable at best, measured in terms of social interaction (Harvey, 1969a). Hägerstrand well recognized that information indeed spread through a communication network interconnecting neighbors, even if as a resultant it superficially seemed to spread in a distance-decay fashion. Consequently his model is not based on the absolute view of space at all. Since the key concept in his explanatory framework is not the distance between neighbors but the communication network linking them, his space view is close to the relationalist's. As a result, however, the relationalist need no longer discuss space, and geography as a "science of space" will not probably take form. At the same time, the absolutist is unlikely to draw any conclusion about space ontology which can perfectly persuade the relationalist. Hereupon we face a dilemma.

But we can find in Hägerstrand's model one way to avoid this dilemma. His space view is certainly relational, but he used distance in estimating the Mean Information Field, which is an operational concept to simulate information spread through a communication network. Hägerstrand's model seems to connote a relational spatial analysis in that an analysis is performed by using spatial elements while maintaining the relational view of space. The explanatory framework described in this chapter sought a functional explanation, so that it is essentially relationalist, but there is no reference to its relation to spatial analysis. Accordingly we need to pay attention to the relational spatial analysis connecting the functional perspective with the sptial perspective again. The relational spatial analysis enables us to practice geography as a "science of space" without falling into the trap of an excessive spatial separatism.

A relational spatial analysis can be performed by applying Multi-Dimensional Saclaing or MDS, which recovers the latent space behind inter-object distances obtained when the functional relationship between objects or their (dis)similarity is defined as distance in a broad sense (Sugiura, 1980). The following is an illustration of this approach's effectiveness, taking an example of the diffusion process of radio subscribers in forty-four major cities and towns of the Tokai district—Aichi, Gifu and Mie prefectures—during the period 1929 to 1933. There are no physical obstacles to interrupt radio waves reception in the study area because all the cities and towns concerned are located in the plain within a 70 km radius from Nagoya, the only city with an NHK radio station during the study period. Sugiura (1981a) reported that even if potential subscribers simultaneously received the same amount of information or influence from earlier subscribers, each of them became a new subscriber at a different time according to occupational differences. This fact suggests that the diffusion process should be investigated with special reference to the interurban interaction related to the communication process and the occupation structure of each city indirectly related to the adoption process. Since these two elements are likely to be spatially covariate to a greater or lesser degree, here the author applied Individual Difference Scaling or INDSCAL, which makes it possible to extract a latent common space behind their spatial covariation (Sugiura, 1981a). The results are summarized as follows.

First, in order to recover a two-dimensional interaction space, the matrix of spatial interaction of commuting workers and students was multidimensionally scaled using M-D-SCAL. In spite of low goodness-of-fit or high stress of 36%, the configuration shows four significant city groups reflecting the sub-areal division of the three prefectures (Fig. 21). Second, to get input data for M-D-SCAL to use in recovering the occupation structure space, a dissimilarity index used by Johnston (1979) was calculated from the

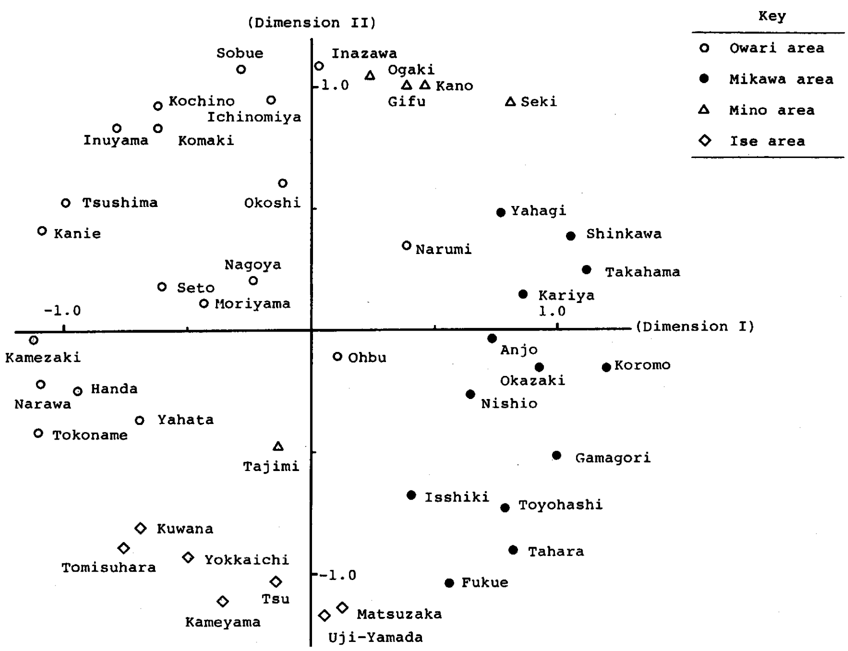

Fig. 21 Two-dimensional interaction space recovered by M-D-SCAL

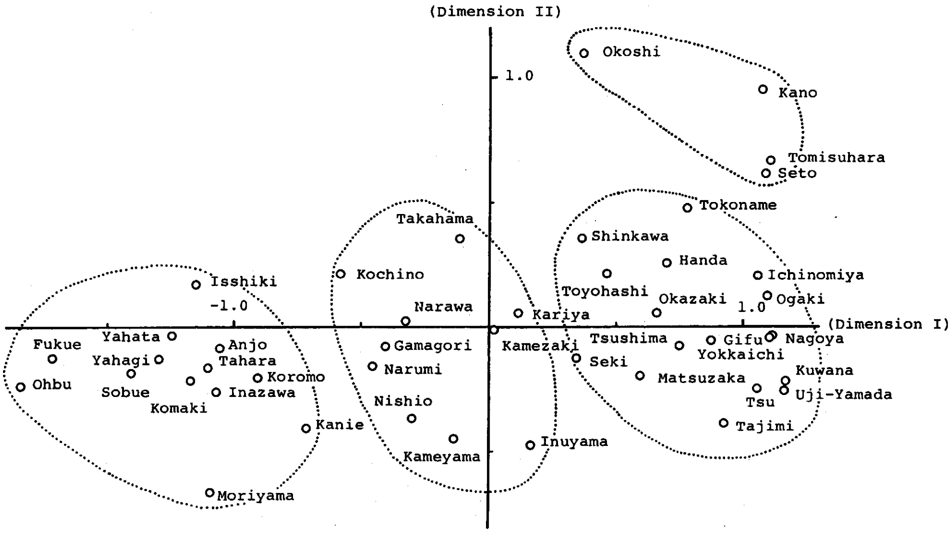

Fig. 22 Two-dimensional occupation structure space recovered by M-D-SCAL

percentages by eight occupational population groups: agriculture, fishery, mining, manufacturing industry, commerce, transportation, service and other. Fig. 22 shows a two-dimensional solution of the occupation structure space, whose stress is as good as 4%. An application of non-metric hierarchical cluster analysis revealed that the first dimension represented a contrast of occupation structure such as agriculture vs. non-agriculture; the second dimension represented the dominance of manufacturing industry among non-agricultural occupations. The set of matrices for inter-city distances in two-dimensional Euclidean space for both was used as input for INDSCAL. As much as 72% of the variance in the matrices was accounted for by the two-dimensional solution. The common space shown in Fig. 23 is, on the one hand, partly characteristic of the occupation structure space: the cities with high non-agricultural occupation rates lie on the left along the first coordinate axis, and those with high agricultural occupation rates on the right. On the other hand, there also appear similar areal clusters as in the case of the interaction space.

To examine the diffusion process in the common space, then, linear through quartic four-variable trend surface analyses (Robinson and Salih, 1974) were applied to the rate of radio subscription for each of the years. It turned out that 77% of the total variance of the diffusion of radio subscription was explained by quadratic trend hypersurface (Table 13). The generalized diffusion process revealed by time-slices of quadratic trend hypersurface (Fig. 24) is as follows: radio subscription first spread from Nagoya to major cities distinguished by non-agricultural occupation structure in the Owari, Mikawa, Mino and Ise areas, and then to smaller cities and towns with high agricultural occupation rates in the Owari and Mikawa areas. In addition, inspection of the residuals suggests that the aspect of population size or urban hierarchy is not well reflected in the common space. With regard to this point, taking into account NHK's and radio dealers'

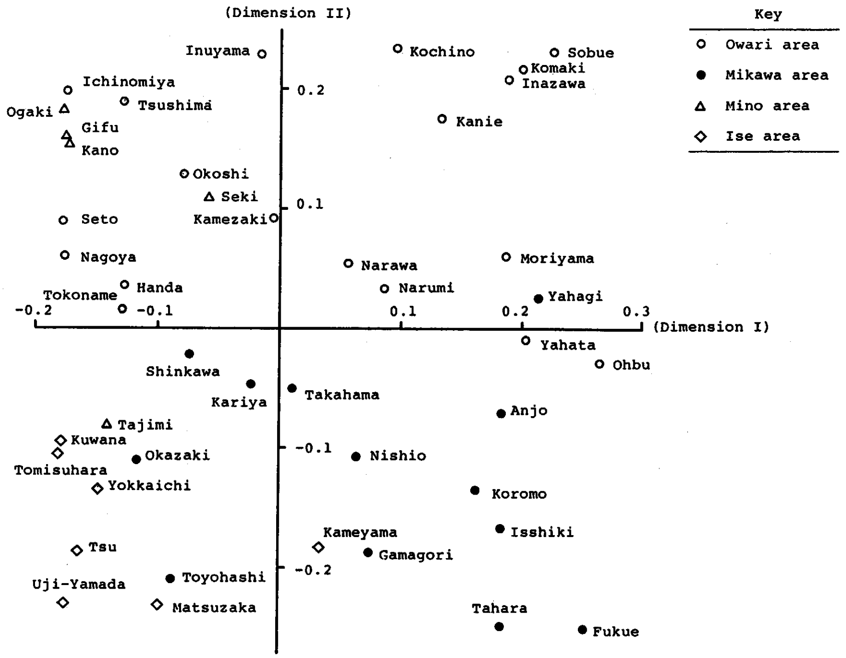

Fig. 23 Two-dimensional common space

Table 13 Results of four-variable trend surface analysis of the rate of radio subscription

Order	%RSS (F-value)	Significant difference between n'th and n+1'th orders (F-value)
1	71.249** (178.426)	0 vs. 1 Yes (178.426)**
2	77.223** (79.109)	1 vs. 2 Yes (9.180)**
3	78.818** (39.168)	2 vs. 3 No (1.506)
4	80.441** (22.378)	3 vs. 4 No (1.023)

** Significant at the 0.01 level

propaganda activities, the trend hypersurface may have a better goodness-of-fit, for example, if data for the market areas perceived by such propagators are added to the INDSCAL input.

One advantage of the relational spatial analysis with the aid of MDS is that the diffusion phenomenon exhibits higher spatial autocorrelation on the space recovered, so

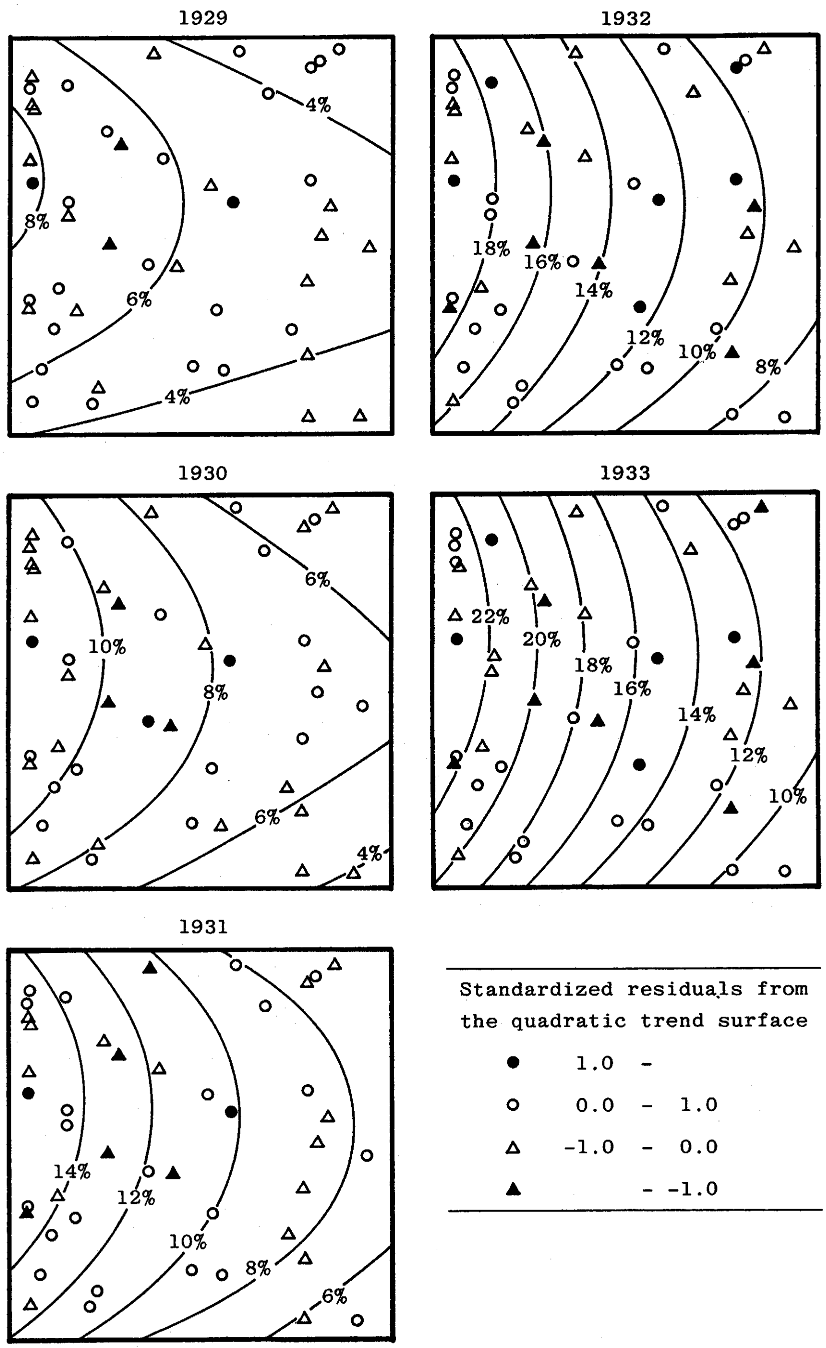

Fig. 24 Quadratic four-variable trend surface of the rate of radio subscription

that a clearer spatial pattern could be identified (Sugiura, 1982). The particular advantage of the INDSCAL approach to spatial diffusion of innovation consists in the following point. The spatio-temporal logistic model, which has usually been used to analyze household innovation diffusion, takes in only the distance to specific places such as origin point of diffusion or central places (Bahrenberg und Loboda, 1973; Hanham and Brown, 1976), but what the distance points at is unknown: the opportunity to get the innovation or access to information. In contrast, when a household innovation diffusion depends upon 1) propagator's market selection, 2) interaction between diffusion agencies or previous adopters and potential adopters and 3) difference in resistance level according to individual differences in social and economic attributes, for example, the relational spatial analysis with the aid of INDSCAL allows recovery of a common space to 1) perceived market area space, 2) interaction space and 3) socio-economic hierarchy space as illustrated by the preceding analysis, or another "common" space combining all the dimensions of these separate spaces—a super-space (Carroll and Chang, 1970, pp. 284-285). Thus, while the spatio-temporal logistic model seems to perform a spatial separatist's analysis, the INDSCAL approach allows a spatial analysis under the functional perspective. In conclusion, the author would like to present such a relational spatial analysis as a major approach to spatial diffusion research on innovation.

6. Conclusion

Spatial diffusion is one type of spatial process. Spatial agglomeration is in a directly opposite position to spatial diffusion, which is defined here as a phenomenon in which an event concentrates in one or a few places within a given area through time. Both diffusion and agglomeration involve birth or increase in objects and death or decrease in objects. Taking into account increase and decrease in the number of objects together with the bipolarity of diffusion vs. agglomeration, we can set up four types of spatial process (Fig. 25). Getis and Boots (1978) located agglomeration as well as diffusion in spatial process research. They fragmentarily illustrated, however, the possiblity of applying the stochastic model to agglomeration research. Theoretical and/or substantive work on agglomeration as a spatial process must await future research.

The same will also be true of diffusion research dealing with decrease in objects. Suggesting the applicability of the same explanatory framework as in the case of increase in objects, Pitts (1962) has pointed out a retrospective use of the Monte Carlo method. Barker (1977) termed this phenomenon "paracme", and Jones (1978) studied the disappearance of the tramway in this context. Whether or not death-type diffusion can be analyzed within the same explanatory framework as birth-type diffusion will likewise await future research.

The present study is concerned with innovation diffusion equivalent to birth-type diffusion. In Chapter 2 the work of Hägerstrand, the substantial initiator in this field, is reviewed and the problem is pointed out: his explanatory framework is communication-biased in spite of his conceptualization that innovation diffusion consists of the two processes of communication and adoption. However, it seems premature to negate a

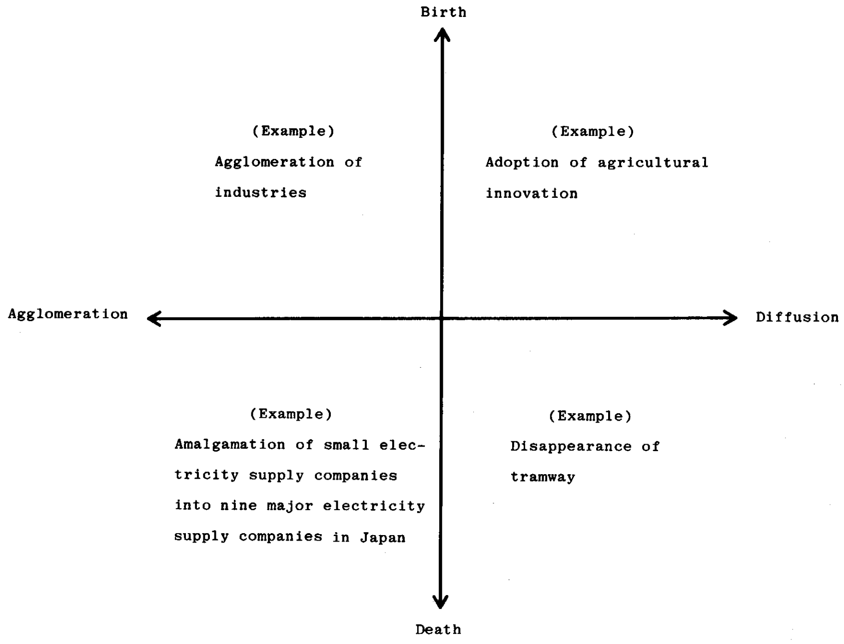

Fig. 25 Types of spatial process

body of the research products for that reason only. The present study thus attempts first to clarify what explanatory framework could be applied to, and second to prepare a new explanatory framework for what it cannot be applied to.

In Chapter 3 the appropriateness of Hägerstrand's explanatory framework is ascertained for diffusion phenomena where the communication process is the dominant factor. Examples are the 1771 Okagemairi and the Spanish influenza epidemic. These two examples are selected because they seem to be suitable for the study purpose, in that they are not innovations themselves but are diffusion phenomena spreading through personal contact.

First, Monte Carlo simulation model analysis of the Okagemairi diffusion revealed that its ellipse-like diffusion from Yamashiro province could be explained by the three factors: the differences in transportation means, such as land route vs. sea route; the physical barrier effect of the Chubu mountains; and religious resistance against the Okagemairi. Second, factor analysis of monthly influenza mortality rates of 46 prefectures in the period 1916-1926 was performed to examine Spanish influenza diffusion. Three epidemic areas were identified—Western Japan, urban areas, and Eastern Japan—and it was confirmed that Spanish influenza spread through the Eastern and Western Japan urban systems as well as the nationwide hierarchical urban system, integrating them into a diffusion channel. From these two case studies, thus, it turned out that Hägerstrand's explanatory framework was to some extent valid for diffusion phenomena mainly dependent upon communication process.

Then innovation diffusions in which the adoption process was dominant and which involved no communication process are examined in Chapter 4. Examples are diffusions of electricity supply companies in Fukushima prefecture and NHK radio stations before World War II. For the former, in which the objective was obtaining profit, acquiring a certain market area is crucial. For the latter, in which the propagator was a non-profit-motivated single entity, efficient facility location is essential.

Discriminant analysis and multiple regression analysis of the diffusion of electricity supply companies revealed that hierarchical diffusion from "city to town" and "town to village" resulted from market area division reflecting the entrepreneur's market preference. The diffusion process of radio stations was analyzed using Törnqvist's facility location model. The result is as follows: openings in the early period were reasonable in terms of maximizing efficiency; after the middle period, however, the efficiency-maximizing principle was likely to be applied to potential adopter-cities chosen on the basis of proximity to larger cities, centrality, and quality of radio waves reception. From these two case studies, it turned out that diffusions of electricity supply companies and radio stations were closely related to the decision-making based on "market area division" and "facility location", respectively. Consequently it has been suggested that an alternative explanatory framework to Hägerstrand's should be prepared for these kinds of diffusion phenomena.

A more comprehensive explanatory framework is explored in Chapter 5. On the basis of the basic elements of Hägerstrand's explanatory framework, it seems to be necessary to classify innovation types and to reexamine their corresponding diffusion mechanisms. Innovations can be categorized into household and entrepreneurial innovations. Entrepreneurial innovation is further classified into four types according to decision-making structure (centralized vs. decentralized) and whether the entrepreneur is profit-motivated or not. In particular, diffusion of entrepreneurial innovation with a centralized decision-making structure should be analyzed in terms of dynamic facility location. In addition to information transmission, threshold conditions permitting innovation adoption are significant in analyzing diffusion of entrepreneurial innovation with a decentralized decision-making structure. For household innovation diffusion, on the other hand, establishment of diffusion agencies should be taken into account, as it largely determines potential adopters' access to an innovation. Thus the diffusion pattern of household innovation is roughly shaped with reference to diffusion agencies. Hägerstrand's explanatory framework therefore specifies the communication process in the final stage after a roughly shaped diffusion pattern is produced.

This explanatory framework embraces Hägerstrand's. It regards entrepreneurial and household innovation diffusion as a chain of events because the diffusion agency is usually entrepreneurial innovation itself. Finally, it has been substantiated that spatial analysis based on this explanatory framework can be performed by applying MDS.

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