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A CROSS-SECTION ANALYSIS OF URBANIZATION IN THE TOKYO METROPOLITAN REGION

By Hiroyuki YAMADA*

I Introduction

During the period of high economic growth after World War II, cities in Japan have experienced radical changes by rapid concentration of population and economic activities into urban areas. Especially, in major large cities, there have been caused many serious urban problems, such as housing shortage, traffic congestion, pollution, etc.

The basic question is how to solve these urban problems and to find the proper urban policies. Urban policies in Japan to date seem to have not been systematically organized, but separate policy has been adopted for individual problems such as the housing policy for housing problems and the urban transport policy for transport problems. Each of those problems, however, is interrelated with each other, and a separate policy for an individual group of problems often tends to aggravate some other problems and prevent the solution of urban problems as a whole.

This problem have been overlooked from lack of the viewpoint of understanding urban changes totally. In seeking the proper policies to solve urban problems, therefore, it is

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The research, on which this paper based, has been done while the author was a visiting research fellow at the Research Institute of Economic Planning Agency, Japan, 1973–75, with the help of many researchers in the Institute, and was published in "Tokyo Daitoshiken no Kenikikozo (The spatial structure of urbanization in Tokyo Metropolitan Region)", (in Japanese) Economic Analysis, No. XX, 1974. Though the author is grateful to all people who helped him at the Institute, he is specially indebted to Mr. Yoshikuni Kobayashi and Makoto Kondo for their collaboration.

necessary to understand the evolution of urban structure or to grasp the nature of changes in urban system as a whole. Then, we must analyse by what forces and with which mechanism urbanization has proceeded.

As a preliminary work for this purpose, it is necessary to see how urbanization has been actually developed in each area. To do so, we must in the first place define the urban area to be studied. In the case of analysing Tokyo, for example, it would not make sense to observe only 23"ku"s (wards) of Tokyo or Tokyo-to, because urbanization has extended beyond the administrative areas of Tokyo-to. We should, therefore, consider the whole process of urbanization expanding beyond the boundary of Tokyo-to and should distinguish urbanized area from non-urbanized area to analyse the former as the area for study.

Secondly, for the purpose of deeper understanding urban changes, it is necessary not only to observe how urbanization extends spatially, but also to analyse what kinds of indices can be employed to comprehend urbanization.

There are, of course, a great number of indices which represent urban characteristics or urbanization, so we must investigate the question of which of many indices are the most representative ones. In some cases we need to create artificial indices which show the level of urbanization on the basis of a number of indices.

The third point to be considered is to comprehend the internal structure of the urban area, taking into consideration the important studies made by urban sociology and geography.

Now, the spatial distribution of activities, or the internal structure of an urban area can be observed from the following two aspects. One aspect is related to the spatial distribution and arrangement of various urban functions within an urbanized area. With regard to this aspect, one can refer to the hypothesis of "concentric circles" by E. Burgess, an urban sociologist, and also to the "sector theory" by H. Hoyt. It is quite important to verify how these hypotheses conform to the reality of Tokyo urban area in comprehending the internal structure of the area.

The other aspect is related to whether urbanization extends continuously from the centre of a city to the peripheral rural area. There has been in the past a way of thinking which argue that there is a quite clear distinction between urban and rural areas and on this assumption emphasize the antagonism between urbanity and rurality. On the contrary, however, there has appeared the theory of "rural-urban continuum" which argues in the process of urbanization that urban characteristics decrease quite continuously from the downtown to the periphery. If one interprets this hypothesis literally, urban characteristics would diminish so continuously from the centre of a city towards the neighbouring rural areas that it would be very difficult to draw a line to distinguish urban area from rural area. That is to say, urbanity and rurality could not be distinguished definitely, since urban characteristics would fade out in continuity.

Is this "rural-urban continuum" theory valid in the case of Japan? In this respect one can see a study by Mr. Saburo Yasuda, a sociologist,[1] where he acknowledges this theory. In this study, however, the theory has not been tested on a large urban area such as Tokyo, but it follows a procedure in which the "degree of urbanity" are obtained by a "factor analysis" of a number of cities and then, depending on these results, the "rural-urban continuum" theory is acknowledged. In order to investigate the validity of such theory, isn't it necessary to see directly for a large city whether or not urban characteristics decrease continuously from the centre of the city to the rural area?

The reason why we discuss the "rural-urban continuum" theory here is that the working hypothesis in this paper does not think impossible to distinguish between urban and rural area because of continuous changes in urban characteristics from an urban area to its rural area, but does think it quite possible, on the contrary. But we do not intend to divide the city area from the country by a traditional urban concept, for urbanization is extending beyond the boundary of actual administrative areas.

Our hypothesis is as follows: the suburb of a central city should be considered as urban area; the central city and its surrounding suburb constitute "metropolitan area"; and this metropolitan area and the non-metropolitan area can be distinguished as different areas. We will examine this working hypothesis below. If the hypothesis is valid, we can define an area to be called the "Tokyo metropolitan region" and we can study such area for further analysis.

Now, in the context of above-mentioned discussion we will observe Tokyo as the area for study. The reasons of this are as follows: first, needless to say, it is indeed Tokyo where many urban problems in Japan have arisen in the most serious way, and thus in this sense it is quite reasonable to select Tokyo as an analytic object to consider solutions of urban problems; second, Tokyo is located in the southern end of the Kanto Plain, the largest plain in Japan and satisfies to the greatest extent in Japan the requirement of urban economics which usually constructs models on the premise that a city would be located in a homogeneous plain without specific features.

With regard to the data we will use in the following analyses those of each of "shi's (cities), "ku"s (wards), "machi"s (towns) and "mura"s (villages) (hereinafter referred to as "zones") in the total area of Tokyo-to, Kanagawa, Saitama and Chiba Prefectures, and a part of Ibaraki Prefecture. There are 296 of such zones. As well known, such data based on respective cities, wards, towns and villages are not always appropriate, since these are administratively defined areas and have a great dispersion in their sizes. Those data will be used, however, simply because of the availability of them.

The indices employed consist of demographic and socio-economic variables. Most of the data on these variables are obtained from 1970 National Census on the 296 zones (cities, towns and villages). The variables employed finally in the analyses are 43 variables shown in Table 1. The study was started originally with an analysis using 60 variables including those shown in Table 1. But almost overlapping variables were

1) Saburo Yasuda, "Consideration on the rural-urban continuum theory", (in Japanese) *Toshi Mondai* (*Urban Problems*) 50–2, 50–9, 1959, (which is reprinted in the same author's "*Plans and Analysis of Social Surveys*", Tokyo University Press, 1970.)

Table 1. Indices used in the Analyses

	Indices	Contents
1*	population	
2*	net population density	population ÷ inhabitable area
3	daytime net population density	daytime population ÷ inhabitable area
4*	ratio of population born in the zone	population born and brought up in that zone ÷ population
5*	ratio of population born in other prefectures	population born in other prefectures ÷ population
6	population increase rate	polpuation in 1970 ÷ that in 1965
7	average size of family	total members of ordinary families ÷ number of ordinary families
8	ratio of population by age groups (0～14 years old)	0～14 of age population ÷ population
9	〃 (15—65 years old)	15～65 of age population ÷ population
10*	〃 (66 years old and over)	66 years and over population ÷ population
11	male population ratio	male population ÷ population
12	in-school population ratio	in-school population ÷ population
13	ratio of population with low education level	primary school career population ÷ total school career population
14	ratio of population with middle education level	secondary school career population ÷ the same as above
15*	ratio of population with high education level	higher education carreer population ÷ the same as above
16*	forests and fields area ratio	forests and fields area ÷ total area
17	resident/daytime employed population ratio	resident employed population ÷ daytime employed population
18	flow-out employed population ratio	flow-out (commuting) employed population ÷ resident employed population
19	flow-in employed population ratio	flow-in employed population ÷ working (daytime) employed population
20	ratio of population employed in their residence's area	population employed in the resident ÷ resident employed population
21*	ratio of flow-out population to central 3 "ku"s(wards) of Tokyo-to	flow-out (commuting) population to central 3 "ku"s of Tokyo-to ÷ resident employed population
22*	ratio of flow-out population to 23 "ku"s of Tokyo-to	flow-out (commuting) population to 23 "ku"s of Tokyo-to ÷ resident employed population
23*	ratio of population employed in the primary industry (daytime)	population employed in the primary industry (daytime) ÷ working (daytime) employed population
24	ratio of population employed in the secondary industry (daytime)	population employed in the secondary industry (daytime) ÷ the same as above
25	ratio of population employed in the tertiary industry (daytime)	population employed in the tertiary industry (daytime) ÷ the same as above
26	ratio of population employed in retail and wholesale trades (day time)	population employed in retail and wholesale trades (daytime) ÷ the same as above
27*	ratio of population employed in finance and insurance business (daytime)	population employed in finance and insurance businesses (day time) ÷ the same as above

28	employees/population ratio	employee population÷population
29	ratio population engaged in housekeeping	number of those engaged in housekeeping÷the same as above
30*	tertiary/secondary employment ratio (daytime)	employment in the tertiary industry (daytime)÷employment in the secondary industry (daytime)
31	resident employed population ratio	resident employed population (nighttime)÷population
32*	while-collar ratio (resident)	while-collar population÷total employed population by job classification
33	blue-collar ratio (resident)	non-white-collar population÷the same as above
34	ratio of skilled workers (resident)	number of skilled production workers÷the same as above
35*	DID (Densery Inhabited District) population ratio	DID population÷population
36	DID area ratio	DID area÷total area
37	house-owner family ratio	number of house-owner families÷number of ordinary families
38*	ratio of tenant families in public housing	number of tenant families of public housing÷the same as above
39*	ratio of tenant families in private rental houses	number of tenant families of private rental houses÷the same as above
40	per capita floor space ("tatami" space)	"tatami" space per family×number of ordinary families÷total members of ordinary families
41*	time-distance from Tokyo Station	
42*	ratio of telephones to population	number of telephones opened÷population $\times 10^4$
43*	ratio of telephones to daytime population	number of telephones opened÷daytime population $\times 10^4$

Note: 1. Figures with asterisk show values transformed into logarithms.
2. Inhabitable area=total area−forests and fields area.
3. Daytime population=population+flow-in population−flow-out population.
4. Flow-out population=flow-out (commuting) employed population+flow-out in-school population.
5. White-collar population=those employed in professional and technical jobs+those employed in management jobs+those employed in administrative jobs.
6. Blue-collar population=mining and quarry workers+those employed in transport and communication+skilled workers and unskilled laborers+those employed in safety watching jobs+those employed in service jobs.

excluded and 43 variables remained.

Outlines of these variables are as follows: (1*) population is the population size of each zones; (2*) and (3) represent population densities which show the extent of population agglomeration both in the nighttime and daytime; (4*) and (5*) are rates of population born and brought up in the relevant zone and of that born in other prefectures, which indicate the stability or mobility of population in the long run; (6) is the population increase rate showing population change of each zone, which constitutes only one dynamic variable in these analyses; the size of family (7) may suggest an increased tendency towards nuclear families; three variables in (8)–(10*) show the age group composition of population in each zone; the ratio of male population in (11) indicates a sexual unbalance in cities; (12)–(15*) are variables concerning education level and in-school population which suggest a tendency towards higher education level; the ratio of forests and fields in (16*) is employed in the context to divide land roughly into inhabitable area and uninhabitable area; indices in (17)-(19) concerning the rates of flow-in and-out (commuting) employed populations may reflect each zone's characteristic as a residential or business area; (20) is the ratio of population working within the relevant zone itself, which shows the self-sufficiency of that zone; variables in (21*) and (22*) represent the extent of connection with the central city; indices in (23*)-(27*) and (30*) reflect the employment structure; (23*), (24) and (25) show the industrial structure and in (26) and (27*) are shown population employed in wholesale-retail trades and finance-insurance businesses which perform central functions of a city, (28) and (29) show populations of employees and those engaged in housekeeping; in addition, it must be noted that the variables in above (23*)-(27*) and (30) are taken up as the data for employment zone (therefore, as daytime data); the ratio of employed population in (31) represents a kind of (a reciprocal of) the coefficient of dependents; indices of (32*)-(34) roughly reflect populations by job; (35*) and (36) are variables of DID,[2] which are considered as indices of urbanization; (37)-(40) reflect housing situation; and indices of (41*)-(43*) indicate kinds of accessibility.

As shown in Table 1, almost all of 43 variables above mentioned are normalized by appropriate denominators. And for all series of so normalized variables, charts of frequency distribution have been prepared. Then, all of those which can approach to normal distribution by logarithmic transformation have been treated logarithmically.

II Some Important Indices of Urbanization

Before beginning the analysis using all of 43 variables, we will consider the distribution of the most important indices which show the level of urbanization.

1. Population Density

At first, look at Figure 1 which plots the densities of populations with respect to the areas of our study. The figure classifies the population densities into following 6 levels (number of inhabitants/km^2): more than 20 thousands; more than 10 thousands～20 thousands; more than 5 thousands～10 thousands; more than 2 thousands～5 thousands; more than 1 thousands～2 thousands; and 1 thousands or less. It must first be noted that these levels in the Figure show distinct spatial structures which can be described somewhat in detail as follows.

(1) Three "ku"'s in the centre of Tokyo-to, which are the central business district, have the decreasing density of population.

2) DID (Densely Inhabited District) is defined in 1970 National Census of Population as follows:
(1) a census district in 1970 Census is to be considered as a basic unit;
(2) the district which is adjacent each other to a census district with a high population density (4,000 inhabitants and more/km^2) within the border of a city, ku (ward), town or village; and
(3) which has population of 5,000 inhabitants and more, constitutes a Densely Inhabited District.

(2) Tokyo 23 "ku"'s have the feature of a central city—if we take up the zones with more than 10 thousands/km^2 of population density, 23 "ku"'s except Edogawa-ku and Musashino City are included in them.

(3) The central part of Yokohama City can be considered to be an area having the feature of a central business district, and a population concentration of more than 10 thousands/km^2 of population density is observed in Nishi-ku and Minami-ku in Yokohama City.

(4) A westward inclination of high population densities can be a result of historic population agglomeration along the trunk railway lines such as Tokaido Trunk Line, Tohoku Trunk Line and Chuo Line.

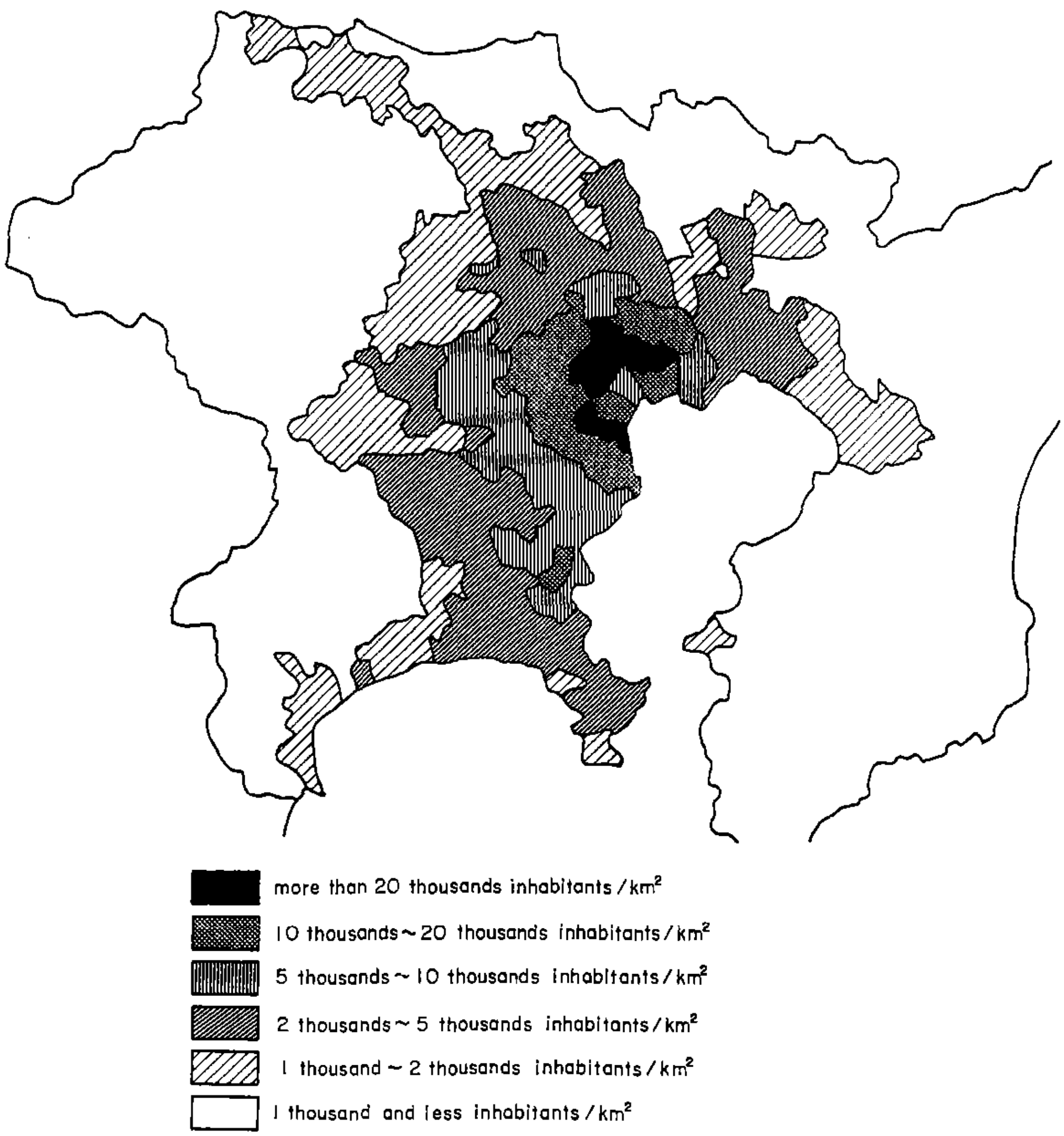

Figure 1. Population densities (net)

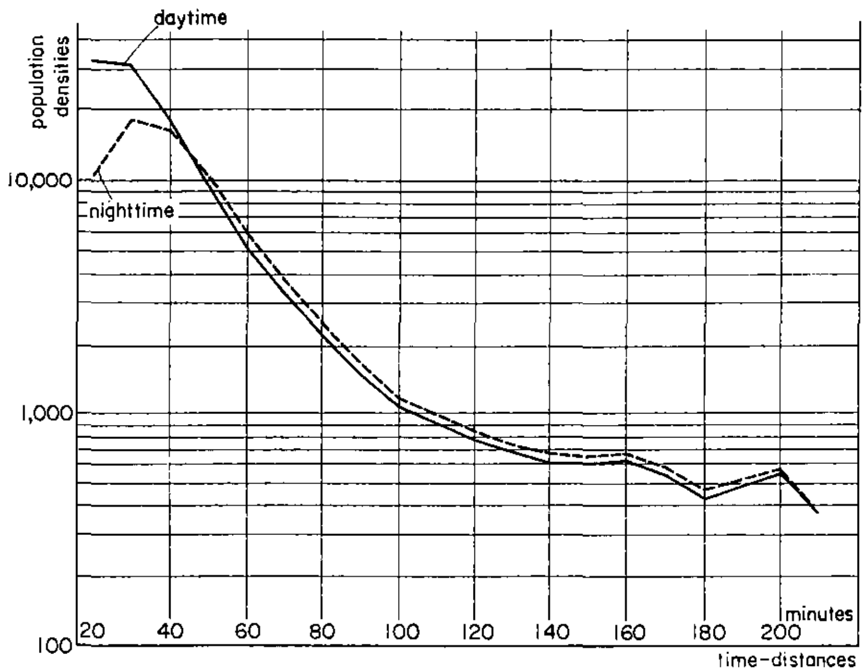

Figure 2. The average population densities

With regard to the point (3), further detailed examination will be made in the analysis of commuting (flow-in and -out) employed population below.

Figure 2 shows the average population densities by time-distances. You can easily see that both the population density and the daytime population density are declining smoothly except in the city centre. An especially significant feature of the city centre is the lowering of the population density, which is sometimes called doughnut phenomenon, and the area of lowering population density in the city centre can be identified with the sphere of 30 minutes timedistance of commuting (exactly speaking, within the 20 minutes sphere from the Tokyo Station as the centre, since the commuting times we used include 10 minutes of access time to the job place from the Tokyo Station).

If we correlate the areal classification made in Figure 1 with the time-distances in Figure 2, we can get the following average time-distance area: the area of population density of more than 10 thousands/km^2—about 50 minutes; more than 5 to 10 thousands—a little more than 60 minutes; more than 2 to 5 thousands—about 85 minutes; and more than 1 to 2 thousands—about 110 minutes. The area of one thousand inhabitants/km^2 density corresponds to the area of about 45 km in an average air line distance.

Now, let us examine the population density functions, here. As seen in Figure 2, there is a quite significant functional relationship between population densities and distances from the city centre. Since this functional relationship itself constitutes an important subject of urbanology, we will present some estimated results concerning it in the following.

One of the most widely used population density functions is the "negative exponential function", which is expressed by the equation $D(x)=D_0e^{-\gamma x}$, where, x=the distance from the city center, $D(x)$ =population density at x point. This function can be derived theoretically under some assumptions, for example, by R. F. Muth and others.[3] When applied this function (using time-distance as x), the following equation was obtained:

$$(1)\quad D(x)=17.137e^{-0.02046x} \qquad \bar{R}^2=0.816,\quad d=0.28$$

According to the equation, it can be said that the gradient independent from the distance, that is to say, the relative decrease rate $\left(-\frac{D'}{D}=\gamma\right)$ is 2.05%.

It may be necessary to note that Durbin-Watson ratio[4] is very bad in the above estimation formula. The reason of this can obviously be seen in Figure 2. Although the figure employs the logarithms of population density, it has nevertheless downward convex curves, and this means that the log-density distance regression as $\log D(x)=-\gamma x$ is not appropriate.

Therefore, as a way of modification, we assumed a function such as $D(x)=D_0x^{-\gamma}$ and obtained the following equation.

$$(2)\quad D(x)=36\times 10^6\cdot x^{-2.170} \qquad \bar{R}^2=0.952,\quad d=0.79$$

Both the correlation coefficient and Durbin-Watson ratio are improved to a significant extent. In this case the relative decrease rate is: $-D'/D=\gamma/x=2.170/x$, which diminishes with the increase of distance.

Another idea is to consider a quadratic equation and to employ the function of $D(x)=D_0e^{-\gamma(x-\beta)^2}$. According to this function, the population density decreases with the increase of x, but after arriving at its minimum value the density begins to increase again. This may be adaptable to explanation of the population density variation from the city centre, through the metropolitan area, to the next adjacent urban area. Thus, our estimation result was:

$$(3)\quad D(x)=481e^{-0.00018(x-176.8)^2} \qquad \bar{R}^2=0.976,\quad d=1.60$$

According to this, at the point of about 177 minutes of time-distance the influences of the Tokyo metropolitan area balance with those of surrounding cities, and the population density at that point is inferred to be 480 persons/km^2. The relative decrease rate in this model becomes $-D'/D=2\gamma(x-\beta)=0.00036(x-177)$, which varies linearly with the increase of distance. Based on three types of estimation above made, it can be said that the relative decrease rate of population density in the Tokyo metropolitan area is not constant in relation to distance.

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3) Muth, R. F., "*CITIES AND HOUSING*: *The spatial pattern of urban residential land use*", the University of Chicago Press, 1969, especially, see Chapter 4.

4) It is considered generally that Durbin-Watson ratio has no meaning in an analysis by cross-section data. In this case, however, zones as samples are connected with each other sequentially and their characteristics will influence each other, resulting the possibility of spatial autocorrelation. Therefore, Durbin-Watson ratio can be employed here as a useful statistics.

2. The Ratio of Population Employed in the Non-Primary Industry

The ratio of population employed in the non-primary industry is usually adopted as an index indicating the economic characteristics of a city. Therefore, we prepared Figures 3 and 4 by the following procedure: based on industry classification in National Census, those employed in industries other than agriculture, forestry, and fisheries and aquaculture are considered to constitute the population employed in the non-primary industry; they are aggregated on the basis of their working places, that is to say, of daytime employed population; and the ratio of the aggregated figure to total employed population is obtained.

In Figures 3 and 4, 296 zones are divided into concentric circles by each 5 km of air-line distancse from the city centre of Tokyo (Figure 3), or by each 10 minutes of commuting time-distances[5)] from it (Figure 4), and for the zones included in each belt the average ratio of population employed in the non-primary industry is calculated. Hereinafter, the graphs (continued lines in both figures) are called the average ratios by (air-line or time) distance circles. Further, both figures also show the results which have been treated in moving-average weighted by the ratio of 1 : 2 : 1 in relation to adjacent circles.[6)] Hereinafter, these graphs (dotted lines in both figures) are called the weighted average ratio by distance circles.

With regard to the average ratio by distance circles, it must be noted that the number of zones (that is, samples) is quite small in the city centre and in the periphery, and therefore, especially in the periphery the average values vary to a great extent depending on whether the samples of that circle consist only of towns and villages or of cities besides them.

For example, the number of samples in different air-line distance circles are given in Table 2, where the values in the 95 km circle and 100 km circle are both meaningless. Also, from the 70 km circle (or the 65 km circle) onward the average values vary to a great extent, and this is because of (i) samples of the 65 km circle and 70 km circle consist only of towns and villages, which (ii) the 75 km, 80 km, 85 km and 90 km circles include 5 cities (29% of all samples there), 2 cities (13%, similarly), 2 cities (18%, similarly) and 1 city

5) The commuting time is calculated as a sum of the time from home to the nearest station (10 minutes), that from the station to Tokyo Station and that from Tokyo Station to the job place (5 minutes). The nearest station is considered a railway (trunk line) station located in the geographic centre of that area (city, ku(ward), town or village). The railway line taking the shortest time to Tokyo Station in train schedules is selected, and it is assumed that each change on the way takes 5 minutes.

6) Both air-line distance and time-distance used here are measured by the distance from Tokyo Station to the commuters' nearest station located in the geographic centre of each city, ku(ward), town or village, as mentioned in Note 5. And by this distance or time distances we have classified those cities, ku(ward)s, towns or villages. Although the data we used are those collected on the basis of each city, ku(ward), town or village, sometimes the area of a city, ku(ward), town or village extends over two or more distance circles and does not always correspond to the relevant distance circle. Moreover, since the characteristics of each distance circle can be assumed to vary continuously, it should be determined not only by those of cities, ku(ward)s, towns or villages within the circle, but also by adding those of the adjacent cities, ku(ward)s, towns or villages. For this reason, we weighted the characteristics of a distance circle with 2 and those of the adjacent circles with 1.

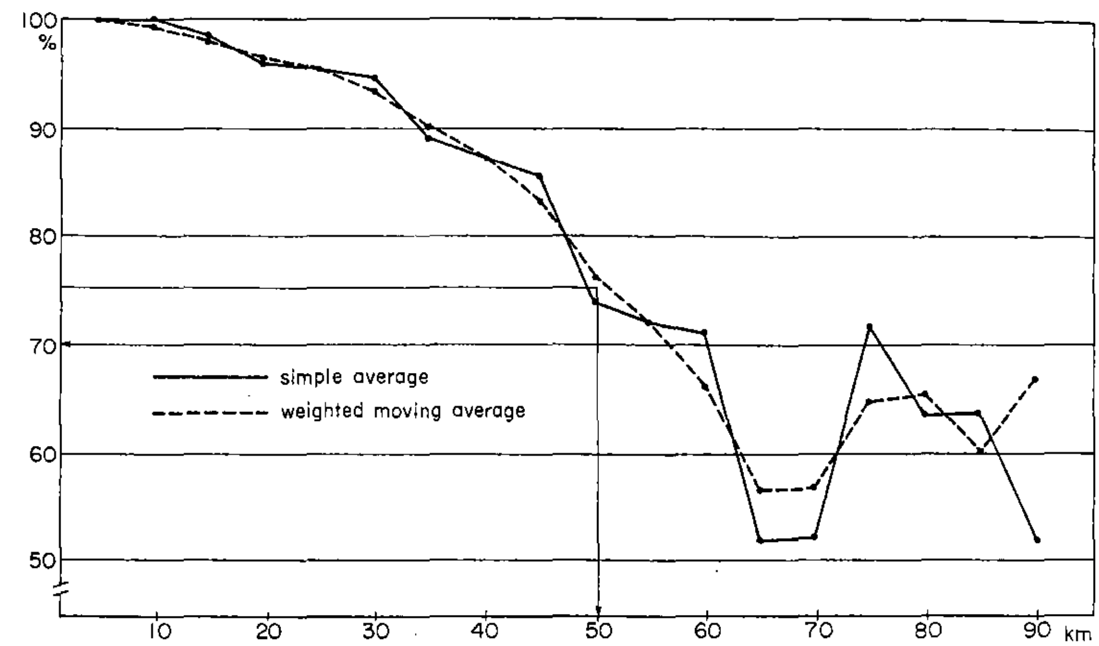

Figure 3. The average ratio of population employed in the non-rpimary industry by air-line distance circles.

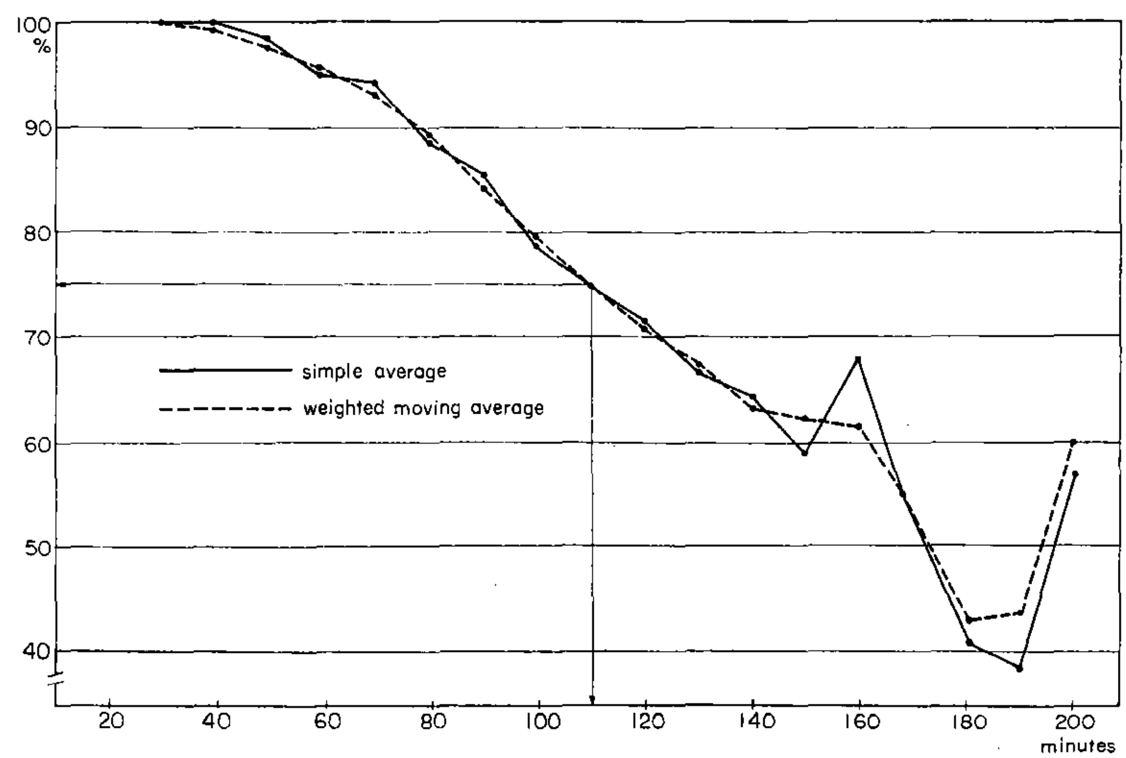

Figure 4. The average ratio of population employed in the non-primary industry by time-distance circles.

Table 2.

circle area	number of zones	circle area	number of zones
5 km radius	5(5)	55 km radius	19(3)
10	13(13)	60	20(6)
15	13(10)	65	19(0)
20	11(9)	70	16(0)
25	18(13)	75	17(5)
30	19(14)	80	15(2)
35	22(15)	85	11(2)
40	20(9)	90	4(1)
45	29(9)	95	0(0)
50	24(6)	100	1(1)

Note: •The air-line distance is taken from Tokyo Station to the centre of each zone and there is no relevant zone in the 95 km circle.
•Figures in parentheses show the numbers of cities or kus.
•The area within the concentric circle of 0∼5 km radius is defined as the 5 km radius circles, and the values attributed to the area were plotted to the circle of 5 km in the graphs.

(25%, similarly), respectively. The same thing is true in the case of time-distances.

As above, we have discussed the irregular variation in the peripheral circles on the basis of statistical treatment. And if we try to give it a positive meaning from the viewpointof metropolitan structure, it can be said that the irregular variation does indicate the existence of satellite cities in the periphery of the metropolitan region.

In the United States and Europe, the standard metropolitan area is usually considered to be the area in which the ratio of population employed in the non-primary industry is 75% and more. It can been seen in Figures 3 and 4 that the circles which satisfy this criterion are approximately the 50 km circle in air-line distance (Figure 3) and the 110 minutes circle in time-distance (Figure 4).

In addition, it must be noted here that the Tokyo metropolitan region has developed toward the west and south, resulting a bias against the concentric circle structure, due to a lag in urbanization in Chiba prefecture. This seems to be caused by many reasons, such as the separation of Chiba by the Tokyo Bay, lower and watery ground in the basin of old Tone River, geographical factors as the existence of Kazusa Platean, and accessibility to Tokaido belt area.

3. The Ratio of Commuting (Flow-out) Employed Population

The ratio of commuting (flow-out) employed population is the most important index indicating the integration of the suburbs with the central city. Therefore, assuming Tokyo 23 "ku"s., Yokohama City (14 "ku"s), Saitama 3 cities (Urawa, Oomiya and Kawaguchi) and Chiba City to be the zone groups which have the possibility to be the central cities, the ratios of commuting (flow-in and -out) employed population of each zone were obtained. The results show that though Saitama 3 cities and Chiba City are local centres, both are weak in the feature of central city and that it is found stronger in

Tokyo 23 "ku"s and Yokohama City. This was true also in terms of population density. The feature of central city in Yokohama, however, is found to be considerably weaker than that in Tokyo 23 "ku"s.

In the case of Saitama 3 cities, there are 11 zones in their suburbs which have 10% and more ratio of flow-out employed population commuting to the 3 cities. But each of these zones has greater ratio of flow-out employed population commuting to Tokyo 23 "ku"s. So, it can be said that a metropolitan area having these 3 cities as the central city does not exist. Next, in the case of Chiba City, there are 4 zones in its suburbs which have 10% and more ratio of flow-out employment commuting to the city, and the ratios of each zone are over than the flow-out ratio to Tokyo. All of these 4 zones, however, are of quite small scale. Finally, in all of "ku" zones of Yokohama City the ratios of flow-out employment commuting to Tokyo 23 "ku"s are more than 10%. Accordingly, even if one can argue the existence of the Yokohama metropolitan area, the area is likely to be included in the greater metropolitan region having Tokyo 23 "ku"s as a central core.

Therefore, we will now observe the average ratio of commuting (flow-out) employed population to Tokyo 23 "ku"s by time-distance circles. Figure 5 shows this. In this figure the simple average (continued line) indicates: the flow-out ratio increases gradually from the centre of Tokyo to the 40 minutes circle where it arrives at the peak and decreases in the 50 minutes circle where commuting zones other than Tokyo 23 "ku"s begin to appear; after that it reaches the maximum again in the 60 minutes circle, and around the 60 minutes circle where some zones have the commuting ratio of more than 50%. After arriving at the maximum value (41%), the commuting (flow-out) ratio turns to decline. Especially, it decreases radically in the 70 minutes circle, since this circle includes the central part of Yokohama City.

Finally, we will consider the ratio of flow-in employed population which constitutes one of the criteria in setting up the SMSA (Standard Metropolitan Statistical Area) in the

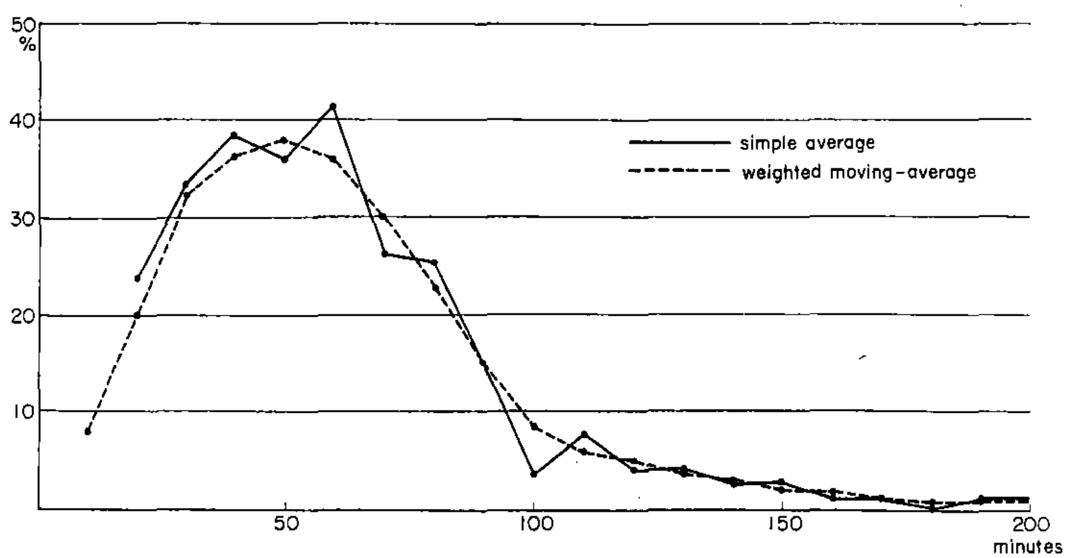

Figure 5. The ratio of average commuting (flow-out) employed population to Tokyo 23 "ku"s by time-distance circles.

United States. Then, we find: outside Tokyo 23 "ku"s, the central city of our object area, there are only 8 zones where the ratios of flow-in employed population from Tokyo 23 "ku"s are more than 10%; all of these 8 zones are adjacent to or in the suburbs of Tokyo 23 "ku"s, and the flow-in employed population ratios to these zones are less than their flow-out employed population ratio to 23 "ku"s. This means that in the Tokyo metropolitan region the flow-in employed population ratio does not raise any special problem, since there is a quite strong centripetal tendency in that region.

III The Principal Component Analysis of Urbanization

Our purpose is to understand quantitatively the spatial structure of the Tokyo metropolitan region and analyse the process of urbanization. We have already observed the most important indices indicating it. Each of these indices, however, represents a specific aspect of urbanization, and a total prospect of it cannot always be obtained by following up the individual indices separately.

Therefore, it becomes necessary to prepare some compound, abstract indices out of many indices and to observe the spatial structure totally. An analytic method useful for this purpose is the principal component analysis. The analysis is to integrate a great number of variables into a few, new synthesized variables without deteriorating the quality of information in the former variables as much as possible. That is to say, the method is to extract a few, new dimensions representing the whole variations in order to integrate many variables into a few components (principal components). Here, the explanatory capacities (contribution ratio) of the new, synthesized variables are quantified, and it becomes possible to determine objectively how many such synthesized variables are necessary to be adopted to elucidate somehow completely the whole variations.

Now, the results of the principal component analysis made on the basis of above mentioned 43 indices and 296 zones are described in the following. If we observe the accumulated ratio of contribution shown in Table 3, the first principal component F_1 absorbs 57.7% of total information (that is, the whole variations indicated by 43 indices). Next, the contribution ratio of each principal component from the second principal component F_2 to the 6th principal component are 10.7, 6.8, 3.8, 3.0 and 2.8%, respectively and the accumulated ratio of contribution at the third principal component reached 74.4% and that at the 6th principal component—84.2%. In other words, it can be said that 74.4 or 84.2% of the purpose can be achieved by analysing 3 or 6 principal components instead of examining all of 43 indices.

We will examine below what kind of contents does have each of the first to the third principal components, since three components represent almost three quarters of original information. And if we see the accumulated ratio of contribution at the third principal component for each of the 43 variables, we will find that each variable is elucidated to fairly a great extent except such variables as the population ratio of age group (15–65 years old), the ratio of in-school population, the ratio of forests and fields area, the population ratio employed in finance & insurance business and the ratio of tenant families in public housing. On the other hand, the ratio of contribution of the 4th and following other principal components are less than 4% and there may be no need to take them into consideration. In order to interpret the principal components, Table 3 which shows the factor loading matrix, and Figure 6, 7 and 8 which illustrate the components' scores of each zone will be used.

1. Urbanization—the First Principal Component

The first principal component can be interpreted to show the feature of urbanization. Variables which have higher loading ($|r_{ij}|>0.80$) are listed in Table 4, (the first column =variable number, the second column=title of the variable, and the third column=factor loading).

As indicated in the table, both population density and immigrants' ratio give quite high positive load; families in rental housing, population of higher education; and the ratio of employees/population, especially that of white-collar give also high load in the positive side. In the negative side the ratio of population engaged in housekeeping as well as that of those employed in the primary industry shows high loads. On the other hand, such variables as DID ratios and house-ownerships, indicating the development of urbanization in terms of land use, are also highly correlated with this component. It would be obvious that the above-described characteristics are all those which have been usually considered as representing so-called "urbanization" phenomena.

With regard to the first principal component having the above-mentioned characteristics, Figure 6 illustrates scores of each zone (scores of all components are normalized, average=0 and variance=1). In the figure a concentric circle structure is considerably clear. It must be noted, however, that the circle of zones which have the highest scores (1.5 and more) is not the central 3 "ku"s of Tokyo, but the circle immediately neibouring westwards to them which consists of 8 zones—Nakano-ku (score, 1.65), Toshima-ku (1.62), Shinjuku-ku (1.59), Suginami-ku (1.59), Musashino City (1.59), Shibuya-ku (1.58), Setagaya-ku (1.52) and Meguro-ku (1.50). Accordingly, it would have to be considered that the feature of urbanization represented by the first principal component does not necessary correspond to the features of the central business district. Generally, a sort of a central business district tends to be imagined as the most developed sphere of urbanization. But, if we explain the feature of urbanization by demographic variables, then it is determined by those characteristic described above in the interpretation of the first principal component.

The population density which has already been discussed in Section 2 has the highest factor loading to the first principal component, and the ratio of population born in the zone has the greatest reverse correlation to the first principal component. Consequently, both of them correspond quite closely to the figure of the first principal component (Figure 6) and it is confirmed that each of them has a very distinct concentric structure. These facts prove the validity of the concentric circle hypothesis on the feature of urbanization.

2. Industrialization—the Second Principal Component

The second principal component is rather difficult to interpret, but it can be

Table 3. Factor Loading Matrix $[r_{ij}]$

	Indices \ principal component	F_1	F_2	F_3	F_4	F_5	F_6	$\sum_{j=1}^{3} r_{ji}^2$	$\sum_{j=1}^{6} r_{ij}^2$
	ratio of contribution (%)	57.7	10.7	6.0	3.8	3.0	2.8		
	accumulated ratio of contribution (%)	57.7	68.9	74.4	78.2	81.2	84.2		
1	population	0.85	−0.20	−0.16	−0.04	−0.04	−0.18	0.7881	0.8237
2	net population density	0.92	−0.18	−0.08	0.01	−0.11	0.19	0.8852	0.9335
3	daytime net population density	0.90	−0.26	−0.16	−0.00	−0.09	0.16	0.9032	0.9369
4	ratio of population born in the zone	−0.97	−0.03	0.00	0.03	0.12	0.10	0.9418	0.9671
5	ratio of population born in other prefectures	0.84	0.26	−0.02	0.07	0.10	−0.22	0.7736	0.8369
6	population increase rate	0.54	0.66	0.17	0.08	0.04	−0.34	0.7561	0.8797
7	average size of family	−0.91	0.16	0.01	0.10	0.19	0.06	0.8538	0.9035
8	ratio of population by age groupes (0∼14 years old)	0.05	0.83	0.14	−0.22	0.07	−0.05	0.7110	0.7668
9	〃 (15∼65 years old)	0.46	−0.30	−0.14	0.30	−0.08	−0.29	0.3212	0.5017
10	〃 (66 years old and over)	−0.81	−0.33	−0.03	−0.10	0.01	0.17	0.7659	0.8049
11	male population ratio	0.64	0.34	−0.20	0.31	−0.17	−0.15	0.5652	0.7127
12	in-school population ratio	0.23	−0.57	0.19	0.40	−0.14	0.27	0.4139	0.6664
13	ratio of population with low education level	−0.91	0.08	−0.24	−0.13	0.14	0.14	0.8706	0.9482
14	ratio of population with middle education level	0.83	−0.22	0.10	0.13	−0.09	−0.26	0.7473	0.8399
15	ratio of population with high education level	0.92	−0.10	0.18	0.04	−0.09	−0.11	0.8888	0.9106
16	forests and fields area ratio	−0.48	0.40	0.24	−0.37	−0.11	−0.18	0.4480	0.6294
17	resident/daytime employed population ratio	0.22	0.43	0.75	−0.10	−0.05	0.18	0.7958	0.8407
18	flow-out employed population ratio	0.76	0.27	0.45	0.23	−0.09	0.22	0.8530	0.9624
19	flow-in employed population ratio	0.90	0.01	−0.15	−0.01	−0.03	0.05	0.8326	0.8361
20	ratio of population employed in their residence's area	−0.76	−0.27	−0.46	−0.23	0.09	−0.21	0.8621	0.9672
21	ratio of flow-out population to 3 "ku"s (wards) of Tokyo-to	0.76	0.04	0.08	0.20	0.35	−0.13	0.5856	0.7875
22	ratio of flow-out population to 23 "ku"s of Tokyo-to	0.74	0.07	0.12	0.27	0.41	0.00	0.5669	0.8079
23	ratio of population employed in the primary industry (daytime)	−0.82	0.36	0.27	−0.03	0.13	−0.19	0.8749	0.9288
24	ratio of population employed in the secondary industry (daytime)	0.67	0.52	−0.44	0.06	−0.05	0.10	0.9129	0.9290
25	ratio of population employed in the tertiary industry (daytime)	0.77	−0.41	0.20	−0.35	−0.06	−0.09	0.8010	0.9352
26	ratio of population employed in retail and wholesale trades (daytime)	0.77	−0.42	0.10	−0.32	0.06	0.14	0.7793	0.9049
27	ratio of population employed in finance and insurance business (daytime)	0.70	−0.22	0.07	−0.22	0.23	−0.19	0.5433	0.6807
28	employees/population ratio	0.91	0.17	−0.03	−0.07	−0.12	0.10	0.8579	0.8872

29	ratio of population engaged in housekeeping	−0. 93	−0. 07	−0. 04	0. 05	0. 18	−0. 17	0. 8714	0. 9327
30	tertiary/secondary employment ratio	−0. 10	−0. 69	0. 48	−0. 33	−0. 04	−0. 14	0. 7165	0. 8846
31	resident employed population ratio	−0. 68	−0. 42	−0. 35	0. 25	0. 05	−0. 18	0. 6017	0. 8587
32	white-collar ratio (resident)	0. 92	−0. 01	0. 14	−0. 04	−0. 07	0. 03	0. 8661	0. 8735
33	blue-collar ratio (resident)	0. 73	0. 26	−0. 39	−0. 26	0. 09	0. 25	0. 8526	0. 8908
34	ratio of skilled workers (resident)	0. 47	0. 59	−0. 47	−0. 06	0. 06	0. 27	0. 9899	0. 8700
35	DID (Densely Inhabited District) population ratio	0. 85	0. 00	−0. 08	−0. 15	0. 03	−0. 27	0. 7289	0. 7964
36	DID area ratio	0. 89	−0. 03	−0. 07	−0. 10	0. 00	−0. 19	0. 7979	0. 8440
37	house-owner family ratio	−0. 94	0. 06	0. 09	0. 06	0. 15	0. 03	0. 8953	0. 9223
38	ratio of tenant families in public housing	0. 60	0. 06	−0. 00	−0. 34	−0. 09	−0. 10	0. 3636	0. 4973
39	ratio of tenant families in private rental houses	0. 92	−0. 02	−0. 11	−0. 18	0. 03	0. 00	0. 8589	0. 8922
40	per capita flool space ("tatami" space)	−0. 95	−0. 02	0. 11	0. 07	0. 02	0. 02	0. 9150	0. 9207
41	time-distance from Tokyo Station	−0. 78	0. 28	0. 14	−0. 29	−0. 08	0. 02	0. 7064	0. 7973
42	ratio of telephones to population	0. 69	−0. 25	0. 00	−0. 05	0. 55	0. 08	0. 5386	0. 8500
43	ratio of telephones to daytime population	0. 69	−0. 07	0. 18	−0. 02	0. 56	0. 13	0. 5134	0. 8443

Table 4.

positive side			negative side		
2	net population density	0. 924	4	ratio of population born in the zone	−0. 968
39	ratio of tenant families in private rental houses	0. 921	40	per capita floor space	−0. 945
15	ratio of population with higher education level	0. 919	37	house-owner family ratio	−0. 942
32	white-collar ratio	0. 919	29	ratio of population engaged in housekeeping	−0. 933
28	employees/population ratio	0. 912	7	average size of family	−0. 906
3	daytime net population density	0. 903	13	ratio of population with low education level	−0. 906
19	flow-in employed population ratio	0. 902	23	ratio of population employed in the primary industry	−0. 820
36	DID area ratio	0. 888	10	ratio of population of 66 years old and over	−0. 810
1	total population	0. 852			
35	DID population ratio	0. 849			
5	ratio of population born in other prelectures	0. 841			
14	ratio of population with middle education level	0. 834			

considered to show the feature of industrialization based on the reasons described below. Items which have higher factor loading ($|r_{ij}|>0.4$) are listed in Table 5.

Let us see at first the items which have relatively high positive factor loading. Then, there seem to be presented two characteristics mixedly: the feature as the area of rapid-growing population (represented by such variables as ratio of population of younger age, population increase rate and resident/daytime employed population ratio) and the feature

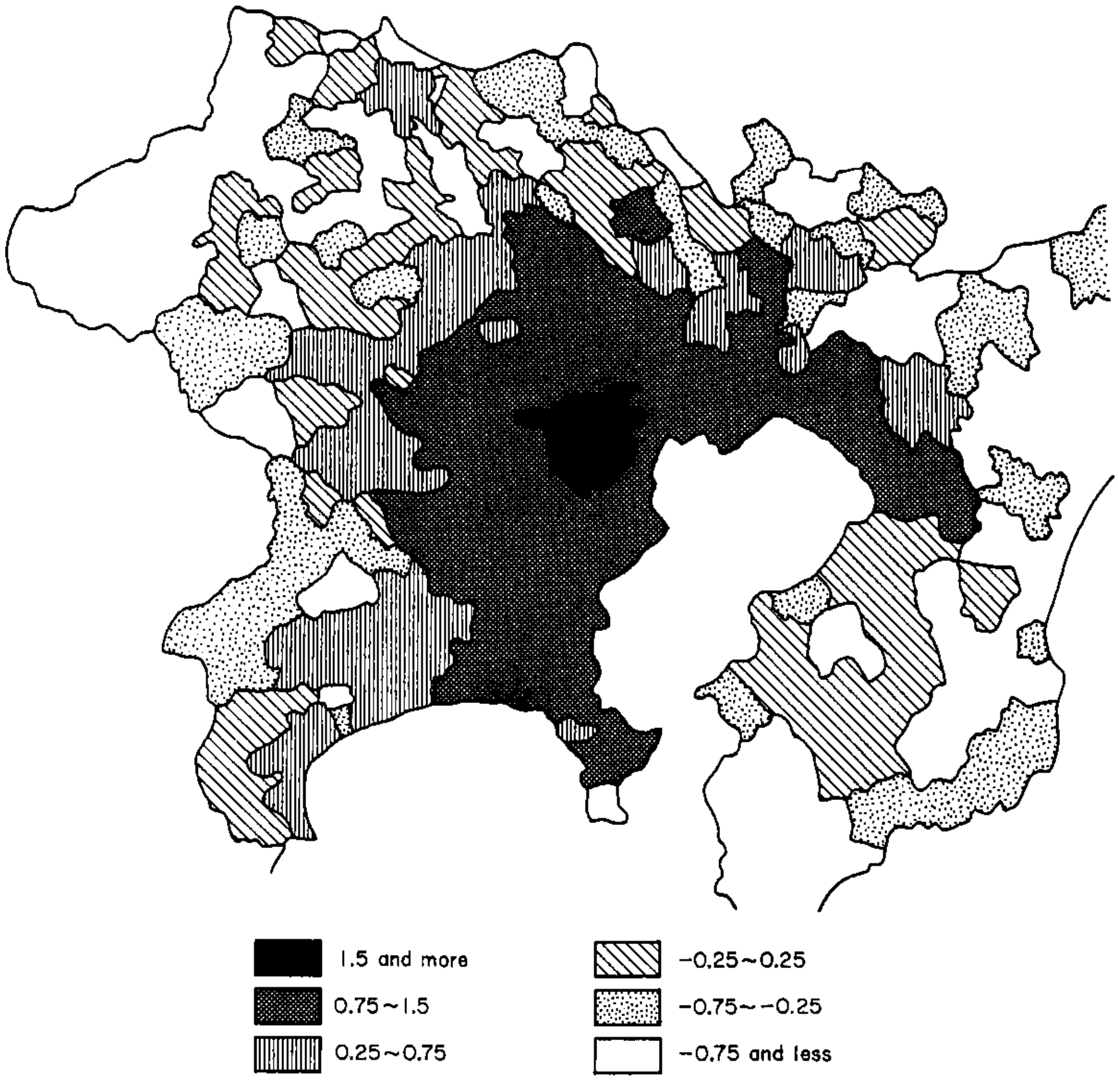

Figure 6. Scores of the first principal component.

Table 5.

positive side			negative side		
8	ratio of population by age group (0~14 years old)	0.836	30	tertiary/secondary employment ratio	−0.687
6	population increase rate	0.657	12	in-school population ratio	−0.571
34	ratio of skilled workers	0.587	31	resident employed population ratio	−0.424
24	ratio of population employed in the secondary industry	0.517	26	ratio of population employed in retail and wholesale trades	−0.420
17	resident/daytime employed population ratio	0.431	25	ratio of population employed in the tertiary industry	−0.409

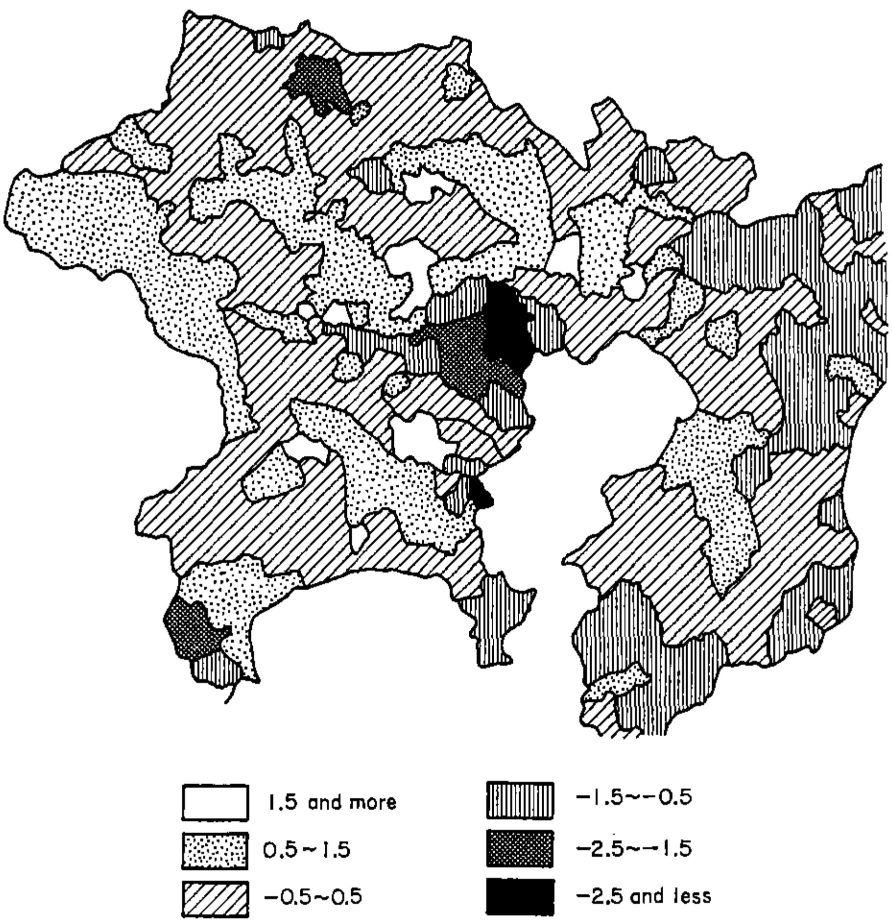

Figure 7. Scores of the second principal component.

as the secondary-industry area (represented by ratio of skilled workers and that of population employed in the secondary industry). On the other hand, if we see the items having relatively high negative factor loading, some of them show clearly the feature opposite to the tertiary-industry area. Others, such as the ratio of in-school population and that of resident employed population seem to indicate the opposite features of area with rapid-growing population. It turns out, as above, that the second principal component combine both of the feature relating to industrial structure and that relating to population mobility. But since the change in industrial structure could be thought to have caused population mobility, it would be proper to interpret this component to show the feature of industrialization.

3. Residential Area—the Third Principal Component

Though it is not so difficult to interpret the feature of the third princiapl component as the second one, it is not easy to name it. But the third principal component may be considered to show the feature of residential area. As we have done before, let us list up items having relatively high factor loading ($|r_{ij}|>0.2$) in the following Table 6.

In the table the variable which has above all the highest factor loading is the ratio of resident/daytime employed population, high level of which indicates a feature of the

Table 6.

Positive side			negative side		
17	resident/daytime employed population ratio	0.749	34	ratio of skilled workers	−0.474
30	tertiary/secondary empolyment ratio	0.476	20	ratio of population employed in their residence's area	−0.456
18	flow-out employed population ratio	0.453	24	ratio of population employed in the secondary industry	−0.440
23	ratio of population employed in the primary industry	0.266	33	blue-collar ratio	−0.388
16	forests and fields area ratio	0.237	31	resident employed population ratio	−0.351
			13	ratio of population with low education level	−0.240

residential area. Such a feature of the residential area is also reflected in that this component has a relatively high positive correlation with the commuting (flow-out) employed population ratio and negative correlation with the ratio of population employed in their residence's zone, respectively.

The third principal component, however, should not be interpreted as representing all features of residential area. Because the first principal component includes a feature of the crowded area and the second one also presents a feature of the area with rapidly growing population. More strictly speaking, therefore, it may be appropriate to express the feature of the residential area in the third principal component as that of the area for mainly residential use, which can be reflected to some extent in the high ratio of resident/daytime employed populations. In this area the tertiary industry has higher weight than the secondary industry and seems to be mainly population-serving businesses. This feature can also be comfirmed by the relatively high rate of flow-out population. On the other hand, as the ratio of population employed in the primary industry and the ratio of forests and fields area have positive values, this area can be seen to be a comparatively suburban residential area. In Figure 8, which illustrates scores of the third principal component, 18 zones with scores of 1.5 and more have strong feature of suburban residential area, located in Tokyo-to, Kanagawa and Saitama Prefectures. (There is no such zone in Chiba Prefecture.)

Though this interpretation of the third principal component was done with regard to positive scores of the component, interpretation from negative sides is also possible. The zones with high absolute values of negative score have a feature of industrial area in contrast with the zones with high positive score having a feature of residential area. Looking at such variables having relatively high negative factor loading as ratio of skilled workers, ratio of population employed in their residence's zone, ratio of population employed in the secondary industry, blue-collar ratio, the negative third component can be said to reflect a feature of the secondary-industry area rather than the tertiary-industry area.

Since we have examined what kind of characteristics do have three principal components, let us try to analyse the regional distribution of those characteristics and under-

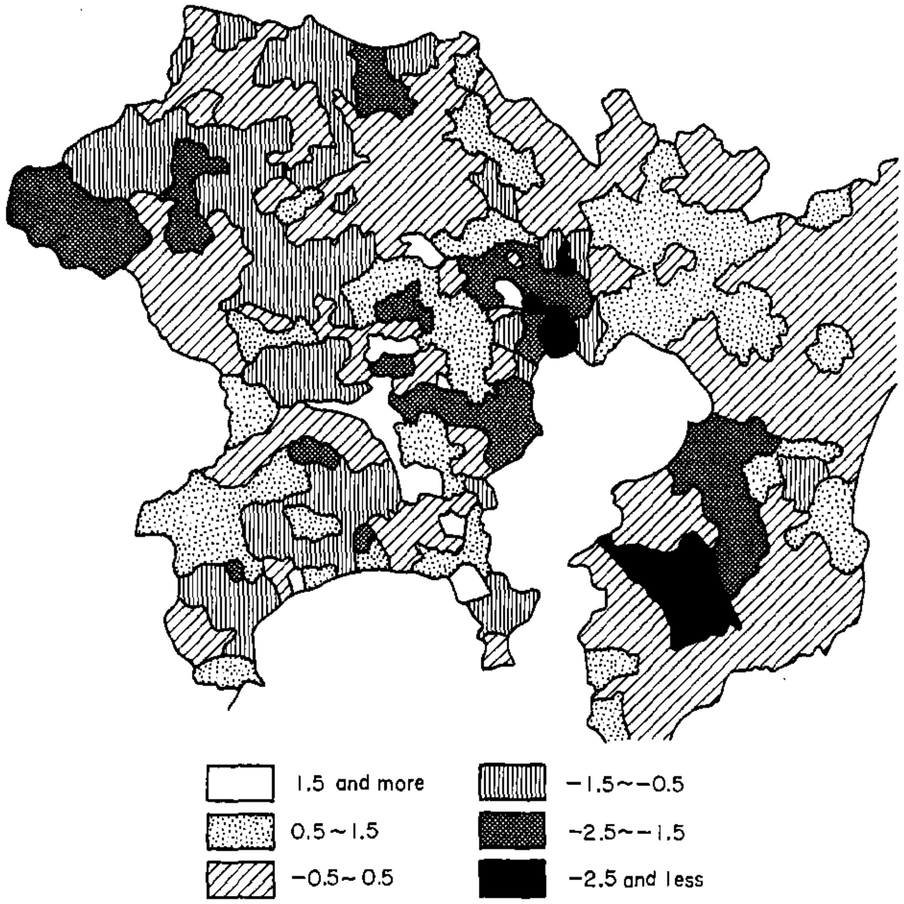

Figure 8. Scores of the third principal component.

stand the pattern of urbanization, by plotting component scores of each zone on a graph.

In Figure 9, scores of the first principal component are scaled on the ordinate and those of the second principal component on the abscissa, and charts of component scores for each zone in Tokyo-to, Kanagawa, Saitama and Chiba Prefectures are overlapped on the graph to depict a conceptional picture, then we get approximately a pattern shown in Figure 9. Next, based on the analysis made above, we can list up roughly the characteristics of each quadrant of the figure as follows.[7]

The I quadrant: the highly urbanized area where the weight of the tertiary industry is high, having a strong feature of the central areas;

The II quadrant: the urbanized area where the weight of the secondary industry is high and population is growing rapidly;

The III quadrant: the area where the level of urbanization is still low, but the weight of the secondary industry is relatively high and population is growing;

7) As it is convenient to make the core areas of Tokyo-to a starting point, here the quadrant where exist the core areas of Tokyo-to (usually regarded to be the IV quadrant) is considered to be the I quadrant.

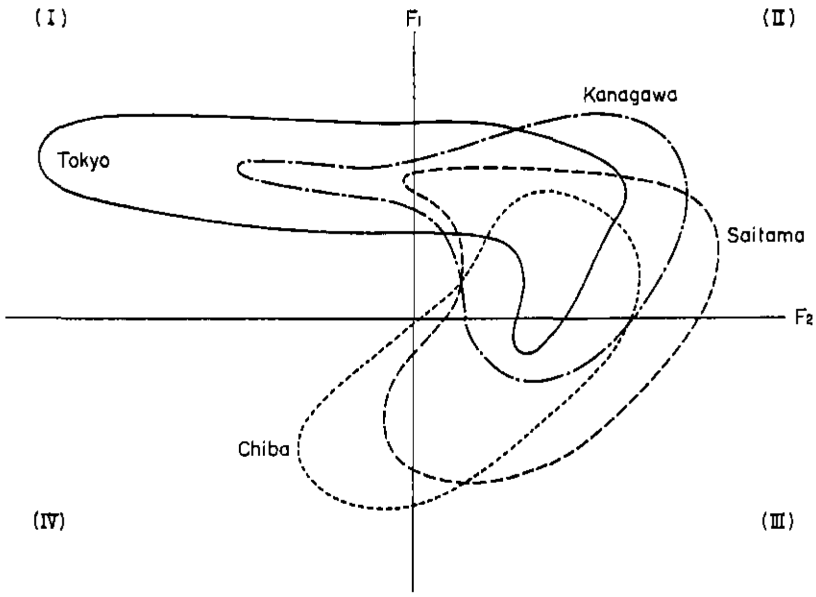

Figure 9. The distribution of the first and second components' scores

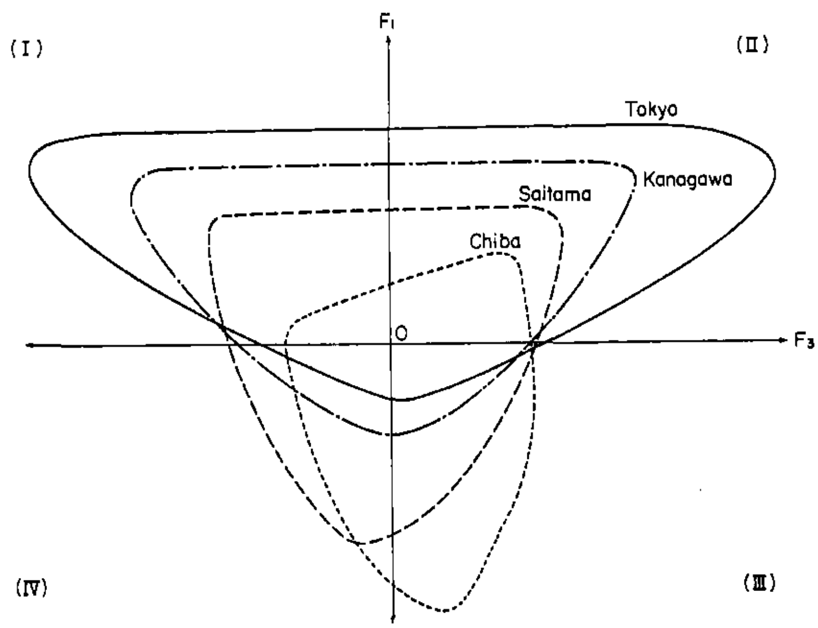

Figure 10. The distribution of the first and third components' scores

The IV quadrant: the area where the level of urbanization is low and depopulation is going on.

Thus, we may consider that the process of urbanization starts from the IV quadrant to the III, then the II and lastly the I quadrants, sequentially. And it is also interesting that we can find a distinctively hierarchical structure of urban development in the area—Tokyo-to and other three prefectures.

Now, we will make similar analysis on the relation between the first and the third principal components. Charts plotted by the scores of both principal components (the first component on the ordinate and the third on the abscissa) in Tokyo-to and other three prefectures are overlapped on the graph to depict a conceptional picture, and Figure 10 is obtained. Based on the analysis made above, the characteristics of each quadrant of the figure may be described as follows.

The I quadrant: the highly urbanized area having a feature of the business area;
The II quadrant: the highly urbanized area having a strong feature of the area for residential use;
The III quadrant: the less urbanized area, which are also weak in the feature of the business area;
The IV quadrant: the area where the level of urbanization is low, but the level of industrialization is relatively high.

Thus, it may be understood in a sense to be quite natural that the graph having the first principal component on the ordinate and the third principal component on the abscissa appears in the shape of an inverted triangle, since the higher the level of urbanization in a region is, the more the diversity of land use increases on the one hand, and in a rual area with lower level of urbanization there arises no higher dispersion either on the positive or negative side with regard to the third principal component, on the other hand. In addition, the distribution of component scores for each zone of Chiba Prefecture is biased predominantly to the III quadrant, indicating the lower level of industrialization there. Moreover, the inverted triangles obtained by plotting the scroes of the first and the third principal components may suggest that there would be two ways of urban development—that is, toward the area with higher level of industrialization or toward the area

Table 7.

pattern	signs of component score			combinations of quadrants		characteristics
	F_1	F_2	F_3	F_1F_2	F_2F_3	
A	+	−	−	I	I	Urbanization and industrialization are well developed and the feature of business area is strong.
B	+	−	+	I	II	The tertiary industry is highly developed and the feature of residential area is strong.
C	+	+	−	II	I	Industrialization is proceeding (and/or) population is growing rapidly.
D	+	+	+	II	II	There appears the complex feature of area with developing industrialization and tendency toward residential area.
E	−	+	+	III	III	The level of urbanization is not high but both industrialization and tendency toward residential area are proceeding.
F	−	+	−	III	IV	The level of urbanization is not high, but industrialization is developing to some extent.
G	−	−	+	IV	III	Urbanization is low and depopulation is going on.
H	−	−	−	IV	IV	

for residential use.

It must also be noted that, in the graph plotted by the scores of the first and the second principal components, zones are arranged in order from the I quadrant to the II quadrant to some extent in the same order as from the centre of Tokyo-to to the suburbs, but in the graph of the first and the third principal components such a relation does not appear. This is connected with the fact that the map depicted by plotting the scores of the third principal component (Figure 8) shows a mosaic structure instead of a concentric structure.

Based on the foregoing analysis, now we may classify all zones into the following eight patterns (listed in Table 7) by combining positive and negative scores of the three principal components.

These eight patterns are arranged in order to the levels of urbanization. Accordingly, this order corresponds approximately to the levels of the score of the first principal component with some exceptions, for example, Nakano-ku which has the highest score of F_I, but belongs to the pattern B. On the other hand, the central areas of Tokyo-to (Chiyoda-and Chuoo-kus) belongs to the pattern A.

IV The Definition of the Tokyo Metropolitan Region

In the foregoing section we have tried to estimate the level of urbanization for each zone and to understand spatial structure of the region by means of the principal component analysis. All these results could give a clue to the definition of a metropolitan region.

However, it is not still clear where we can delineate the metropolitan area. For example, only by the component scores of urbanization (the first principal component) it is hard to decide the zones which should be included in the metropolitan area. The first principal component absorbs about 58% of the information obtained from the data of 43 indices employed, and the scores of this component at a glance vary segmentally in a concentric pattern starting from the centre of Tokyo, which seems to support the hypothesis of rural-urban continuum. Moreovre, although we could shed light on the urban structure of the region by the principal component analysis, the relations between the central city (Tokyo 23 ku area), its suburb and the outer area could not be made clear to a great extent. Can we indeed distiniguish metropolitan area from non-metropolitan area in this region with statistical significance? In this section we will try to tackle this problem. As an approach to do so, we will employ two group discriminant analysis in multivariate statistical techniques.

The data used in the discriminant analysis are the same 43 indices as used in the principal component analysis. At first, we determine 2 zone-groups which are obvious to be included in or excluded from the metropolitan area—that is, urbanized area and non-urbanized area, then discriminant function will be obtained.

Here, based partly on the results of foregoing analysis, the following two criteria for selecting zones belowing to "urbanized area" are adopted.

(a) population density—1,000 persons/km^2 and more;

(b) commuting (flow-out) population ratio to Tokyo 23 "ku" area—25% and more. On the other hand, as the criterion of selecting "non-urbanized area", the following condition is employed;

(c) the ratio of population employed in non-primary industry—65% and less. As these three conditions, especially (b) and (c), have fairly high values, it is needless to say that each zone included in "urbanized area" and "non-urbanized area" confirms to a general image of urbanity or non-urbanity.

The number of sample zones of thus obtained "urban area" is 88 and that of "non-urban area" is 99. Next, according to the data (43 indices) of these 187 zones, discriminant function is to be obtained and by applying this function other 109 zones left undiscriminated are to be classified into either "urbanized area" or "non-urbanized area". As a result of the discrimination of already determined 187 zones, Mahalanobis' distance (D), which indicates the extent of the discrimination capacity, obtains a sufficiently high value (123.7) and the value of F (103.6) for 43 and 143 degrees of freedom is also highly significant. Next, as the means (μ) and standard deviations (σ) of the discriminant function scores for both groups $\mu_1=-0.2820$, $\sigma_1=0.0650$, $\mu_2=-0.9506$ and $\sigma_2=0.0555$ (where, suffix 1 and 2 indicates "urbanized area" and "non-urbanized area") are obtained, respectively, then we can calculate the cutting-off point discriminating between two groups by $(\mu_1\sigma_2+\mu_2\sigma_1)/(\sigma_1+\sigma_2)$ and obtain the value of -0.6427, by which the undetermined 109 zones are classified. As a result, there emerged a picture of the Tokyo metropolitan region approximately similar to that expected by us, but there also appeared several zones which did not satisfy the condition of contiguity.

Now, two groups thus obtained by classifying all zones (hereinafter these groups are called "metropolitan area" and "non-metropolitan area") are tested again in the same way. As a result, Mahalanobis' distance between new two groups becomes 30.6, naturally smaller than that in the above mentioned case, but still high enough and the value of F for 43 and 252 degrees of freedom obtains 45.1, which is still highly significant. Figure 11 gives a diagrammatic representation of what the discriminant analysis has produced.

In the figure the frequency distribution of the new discriminant function scores is shown with the scaling by 0.0025. And assuming normal distributions, the probability density curves are also illustrated according to the means and standard deviations obtained from discriminant function scores of "metropolitan area" and "non-metropolitan area" —that is, $\mu_1=0.0118$, $\sigma_1=0.0188$, $\mu_2=-0.0924$ and $\sigma_2=0.0188$. It can be seen that the discrimination between the two groups has been made significantly.

However, as a result of examining the possibility of misclassification of zones, only three zones were found to be misclassified. As the value of new cutting-off point $\delta=\left(\frac{\mu_1\sigma_2+\mu_2\sigma_1}{\sigma_1+\sigma_2}\right)$ is -0.04025, it turns out that one zone (Oome City) has been misclassified into "metropolitan area" and the other two zones (Odawara City and Futtsu Town) into "non-metropolitan area".

The final results of the discriminant analysis are shown in Figure 12. In the figure, each of both groups is divided into 3 parts, respectively, according to discriminant value.

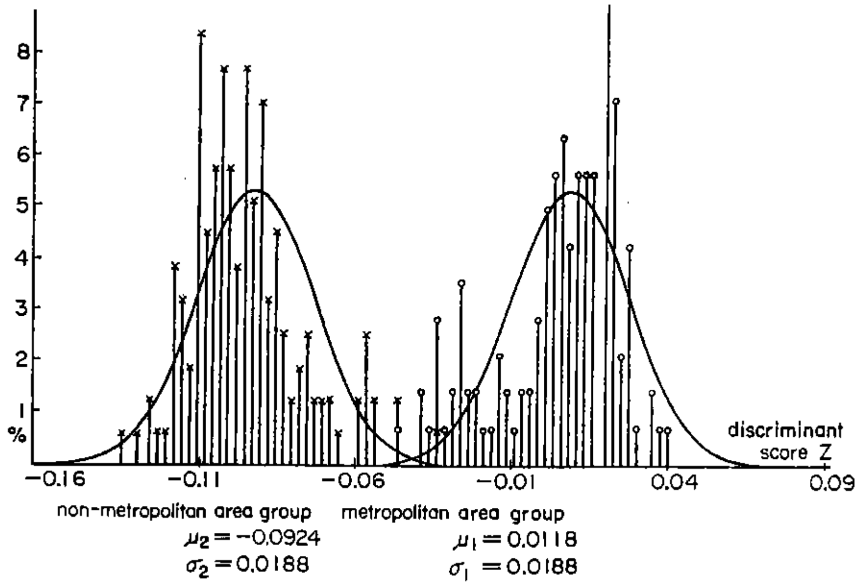

Figure 11. Density Curves of Discriminant Values

To see "metropolitan area" as a whole, we can find that three zones in Kanagawa Prefecture (Odawara City, Manazuru Town and Minamiashigara Town) and also three zones in Chiba Prefecture (Kimizu Town, Kisarazu City and Futtsu Town) constitute separate sub-groups respectively, forming detached zones. These detached zones of the two sub-groups may be considered to be relatively independent urban-areas outside the Tokyo metropolitan region.

Discriminant analysis is a technique of differentiating several groups in such a way that the discriminant function scores for each group are maximally separated from one another, using a set of available variables. It is not always clear whether the discriminant function obtained by the calculating procedure could effectively achieve the purpose—in this case, the discrimination between metropolitan area and non-metropolitan area. In our case, however, there may be no doubt that the discrimination has been successful, judging from its Mahalanobis' distance, the value of F and Figure 11.

This result might be interpreted to indicate a limitation of "rural-urban continuum" theory concerning the urbanization process. Or, at least, it can be interpreted to show the effectiveness of the discrimination between metropolitan area and non-metropolitan area even if "rural-urban continuum" theory is valid. The fact that by the principal component analysis the factor showing the level of urbanization is obtained as the first principal component could be said to demonstrate the rural-urban continuum in one aspect. However if the discriminant function scores would distribute with equal probabilities, probability density curve could not be separated into two curves as shown in Figure 11 and Mahalanobis' distance would approach closely to zero and its value of F would also be insignificant. In such case the validity of "rural-urban continuum" theory would be stronger.

Lastly, let us consider here the relation between the outcome of the discriminant

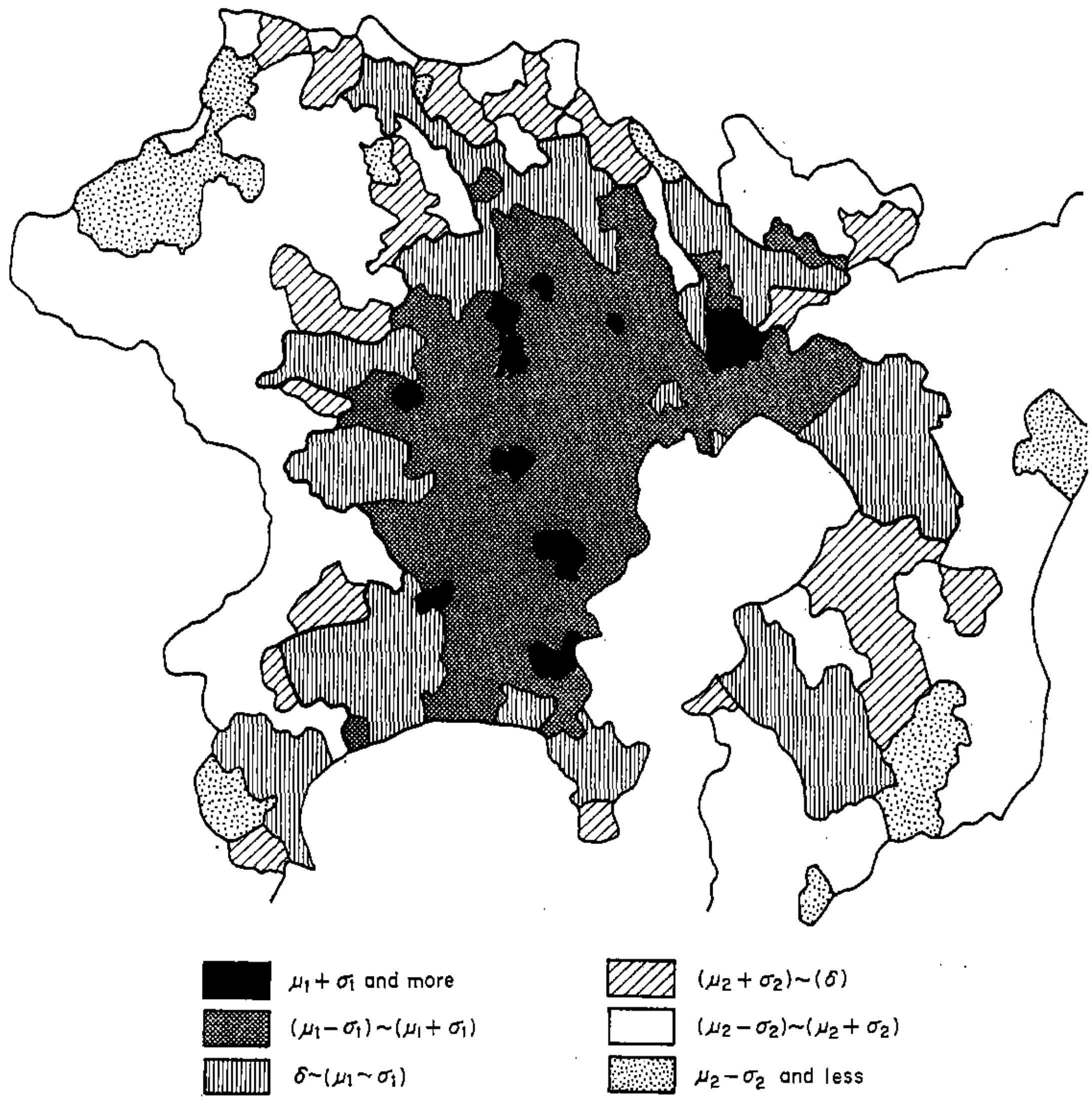

Figure 12. Discriminant value.

analysis and the individual indices of urbanization examined in the second section. The reason is that, since discriminant analysis discriminates between the groups, reducing a great number of variables to a single one, the procedure is quite complex and the analysis is not necessarily simple and plain. So, for example, it is quite troublesome to apply the method to other regions. Therefore it may be sensible to examine whether the results close to those of discriminant analysis can be obtained by employing several individual indices. By overlapping the maps of various individual indices on Figure 12 the following results can be found out. That is, if we delineate an area which includes all zones having discriminant function scores equal to or more than $\mu_1-\sigma_1$ (a necessary condition), and at the same time includes as many as possible those zones as being within "metropolitan area" (a sufficient condition), and consists of zones contiguous to each other (a necessary condition), the area in which all zones satisfies the following two conditions can be obtained.

I. net population density is at least 1,000 persons/km^2 (a), and
the ratio of population employed in non-primary industry is at least 75% (b),
($a \cap b$).

II. the ratio of commuting (flow-out) employed population to Tokyo 23 ku area is at least 10% (c) and, or
the ratio of commuting (flow-out) employed population (anywhere) is at least 25% (d)
($c \cup d$).

An area can be defined by taking an intersection of I and II; $I \cap II = (a \cap b) \cap (c \cup d)$. The area is shown as in Figure 13, in which only 17 zones from 141 zones included in "metropolitan area" dropped out. We may call the area thus obtained the "Tokyo Me tropolitan Region". Then, what are the characteristics of the Tokyo Metropolitan Region thus defined. Zones included in the Tokyo Metropolitan Region are of approximately -0.02172 ($=\mu_1 - 1.7\sigma_1$) and more in terms of the discriminant function scores and of around 0.2378 and more in terms of the first principal component score. The total area of this metropolitan region is 3653km^2, of which the central city (Tokyo 23 ku area) occupies 15.8%, and this region has 20 millions people in the area. Then, net population density of the total metropolitan region is 5,653 persons/km^2, which corresponds to about one thirds of that (15,319 persons/km^2) in the central city, while net population density in the centre of Tokyo-to (3 ku area) is about 9,800 persons/km^2, which is far less than that of 23 ku area and that of the Tokyo Metropolitan Region excluding 23 ku area is 3,839 persons/km^2.

Daytime population in the central city (Tokyo 23 ku area) and in the centre of Tokyo (3 ku area), however, occupy 50% and 10%, respectively, of the total population in the

Table 8.

item	population	population density (per km^2)	percentage in the metropolitan area (%)
Population			
(Tokyo Metropolitan Region)	20, 649, 487	5, 653	100. 0
(Tokyo 23 ku area)	8, 840, 179	15, 319	42. 8
(Central 3 ku area of Tokyo-to)	402, 013	9, 793	2. 0
Daytime population			
(Tokyo Metropolitan Region)	20, 911, 124	5, 724	100. 0
(Tokyo 23 ku area)	10, 432, 520	18, 078	49. 9
(Central 3 ku area of Tokyo-to)	2, 069, 431	50, 412	9. 9
Daytime employed population			
(Tokyo Metropolitan Region)	10, 279, 516	2, 813	100. 0
(Tokyo 23 ku area)	5, 890, 429	10, 207	57. 3
(Central 3 ku area of Tokyo-to)	1, 721, 068	41, 926	16. 7

Notes: Inhabitable area in the whole Tokyo Metropolitan Region—3,653 km^2.
Inhibitable area in Tokyo 23 ku area—577 km^2.
Inhabitable area in the central 3 ku area of Tokyo-to—41 km^2.

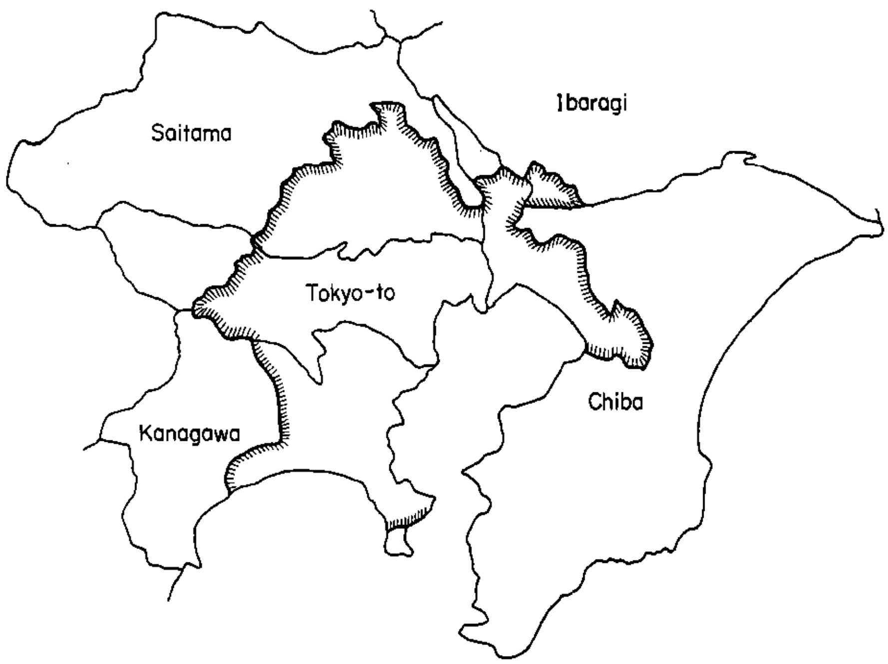

Figure 13. The Tokyo Metropolitan Region.

whole metropolitan region, and therefore, densities of the daytime populations there reach 18,000 persons/km^2 and 50,000 persons/km^2, respectively. Moreover, daytime employed populations in Tokyo 23 ku area and in the centre of Tokyo (3 ku area) occupy 57% and 17%, respectively, of that in the whole metropolitan region (around 10 million persons), and therefore, employed population densities in both areas are approximately 10,000 persons/km^2 and 42,000 persons/km^2, respectively (cf. Table 8).

These are a rough sketch of the Tokyo Metropolitan Region based on the data of National Census of Population in 1970. Using the same difinition of the Tokyo Metropolitan Region, we will be able to trace how Tokyo has expanded and analyze how its population density has changed, causing various urban problems.