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An Analysis of Population Density Distribution in View of the Relations between the Density and Distance from Urban Center in an Urbanization Promotion Area — Sapporo, 1975,1980,1985

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Abstract

The structure of urban space in terms of distribution of population densities and the relations between the density and distance from the urban center are important indices which indicate the extent of the growth of a city. The studies on these, however, have not attained any good results although several attempts have been made by Colin Clark (1967) and some others.

In this paper, a study was conducted based on detailed data collected, during the past 10 years from 1975 to 1985, according to the block unit in the urbanization promotion area of Sapporo, one of the rapidly growing cities in Japan. The result was quite meaningful in that it includes the so-called doughnut phenomenon of the city and also that it is expressed by means of Weibull distribution function, one of the probability functions which show extreme accuracy and availability,

An attempt was also made, in terms of the distance relations of entropy, to grasp the active change of the density in the blocks and the complicated phases of the change. Additionally, the distribution of population densities in the area along the subway lines, the densely inhabited zone in the urbanization promotion area, and outside this area was analyzed quantitatively.

1. The aims and methods of the study

1.1 The aims

Population density is the most basic indicator of the human living conditions. It holds significance for planning of our environment, and particularly for that of urban space.

Population density, however, is treated as a superficial and simple index and is not paid sufficient attention in the academic field, while it is often referred to and used as fundamental data in examining various plans.

The population in urban area is rarely in a stable state. Especially in the case of a big city, which is under the influence of constant change, it is estimated that the population distribution is always fluctuating as more people migrate into the city. In order to prepare

Department of Architecture

data for urban planning, we are urged to quantitatively elucidate the trends in cities, which we feel only subjectively, in terms of objective indices.

The authors of this paper have been interested in the structural change of the population distribution which takes place as the population grows, and have been examining the relationship between population density and distance from urban center. Regarding this

Table 1 The transition of the total populations of Sapporo and the populations, areas, population densities in U. P. Area — 1960~1985

Year	Total Populations (persons)	Pop. Increase in 5 years		Population & it's per cent				U. P. Area	
				in U. P. Area		in other area		Densities	Areas
		Pop.(p.)	Rate(%)	Pop.(p.)	p. c.(%)	Pop.(p.)	p. c.(%)	(p./ha)	(ha)
1960 S. 35	615,628 ⑩	128,237	23.8	—	—	—	—	—	—
1965 S. 40	821,217 ⑨	205,389	33.4	—	—	—	—	—	—
1970 S. 45	1,010,123 ⑧	188,906	23.7	981,000	97.1	29,123	2.9	44.6	22,010
1975 S. 50	1,240,613 ⑦	230,490	22.8	1,207,146	97.3	33,467	2.7	54.8	22,010
1980 S. 55	1,401,757 ⑥	161,144	13.0	1,371,801	97.9	29,956	2.1	59.1	23,220
1985 S. 60	1,542,979 ⑤	141,111	10.1	1,515,325	98.2	27,654	1.8	64.6	23,449

U. P. Area : Urbanization Promotion Area
Number in ○ is the population ranking within 11 large cities.
The numbers of population is on October, 1 of each year

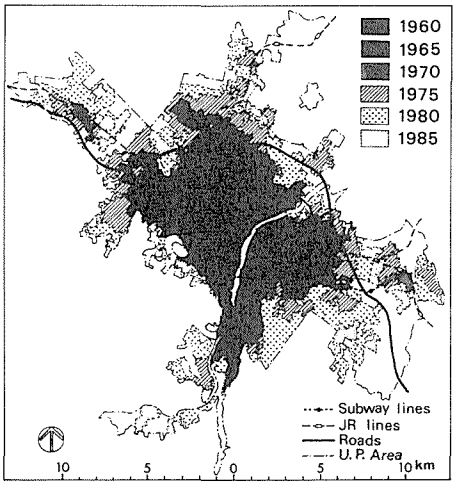


Fig. 1 The transition of DID — Sapporo, 1960~1985

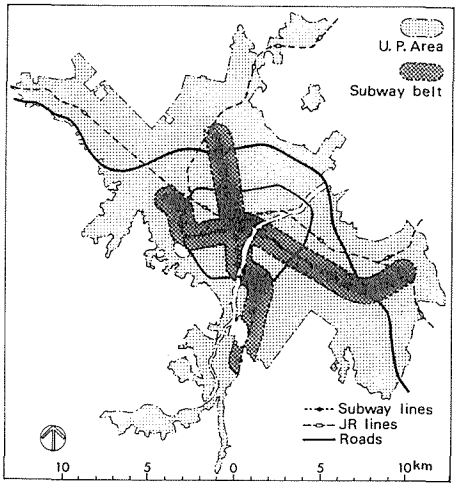


Fig. 2 The Urbanization Promotion Area and the belt of subway — Sapporo

Table 2 The year of construction starting and completion of the subways—Sapporo

subway lines	starting	completion
Nanpoku—line (Makomanai~Kita 24 joh)	1969	1971
Tohzai—line (Shiroishi~Kotoni)	1973	1976
Nanpoku—line (Kita 24 joh~Azabu)	1974	1977
Tohzai—line (Shiroishi~Shinsapporo)	1978	1982

point, a study made by Colin Clark (1967) with London and Chicago as its sample cities is well-known, but it is not sufficient enough to understand the doughnut phenomenon of the present-day urban cities.

We, therefore, have made a survey in Sapporo, based on the distribution of population densities in the urban area, for the purpose of analyzing the mechanism of the change in urban space which takes place with the progress of urbanization. [1),2),3)]

During the past quarter of a century since 1960, the growth rate of the city of Sapporo has always been the highest among the 11 big cities in Japan. The population of the city was 1 million in 1975, surpassed 1.5 million in 1985, and is still increasing year by year. In this paper, Sapporo is the most suitable object in analyzing change in urban space of a growing city and the related phenomena, and also to examine various problems to be solved for urban planning. (Table 1)

Sapporo has an area of 1,118.01km^2, the third largest area as a city in Japan, but 64.5% of which are covered by forests. The Urbanization promotion area of Sapporo is relatively concentrated in plains, and the average population density in this area has been increasing every year, although the density itself is the second lowest following Kita-kyushu among the all big cities in Japan. (Table 1)

As for the transition in the Densely Inhabited Districts (DID), the DID in 1960 were found within a radius of 3 to 6km from the urban center, having an area of 47.5km^2. Then the area expanded rapidly because of the accumulation of population, accelerated motorization, and consolidation of traffic facilities. In 1985, the area was 3.7 times as large as before to become 176.9 km^2, which is a very rapid increase compared with the fact that the population increased only 2.5 times during the same period. The population density in the DID has been on the decrease, and the expansion of space is greater in scale than the increase of density. (Figure 1)

The authors have been studying, from a macroscopic point of view, the population density based on the data collected by the statistical tracts in the past 25 years from 1960 to 1985 according to the rings and sectors.

As a result, we found one distinct direction in the rapid change of density distribution in the area ranging from urban center to its periphery, and also in the tendency of the change, which took place during a short period of time in the growing city. (Figure 3) The studies made in the past by the ring were based on a relatively large space unit and the distance between rings was long and irregular.

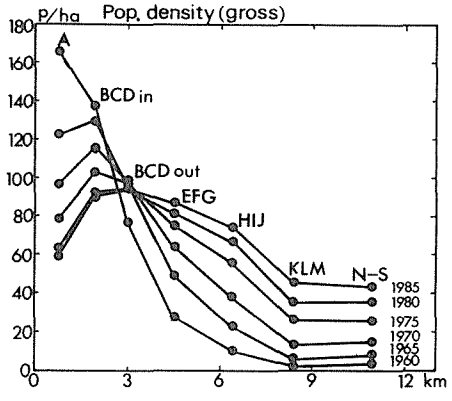


Fig. 3 The transition of population densities for each ring belts in U. P. Area — Sapporo, 1960~1985

What we tried this time was to obtain more accurate distance relation utilizing data based on a smaller space unit.

We also examined by the sector the growth directions of the city, but did not find much diversification among sectors.

The rate of the recent population growth is slower than those before 1975. The 5 years from 1970 to 1975 saw the largest increase in the population of Sapporo. It is estimated that a big change is taking place since then in the structure of population distribution within the urban area.

Based on this recognition, we devoted ourselves to the examination of more detailed data collected by the block unit in the 10 years from 1975 to 1985 to gain a clear understanding of population density distribution in the urban area, its change, and their relations with distance from urban center.

1.2 Areas and methods of analysis

The areas analyzed in this paper are; [1] the whole urbanization promotion area, [2] the zone along the subway lines, and [3] the urban area which is outside of the subway lines area in urbanization promotion area.

The urbanization promotion area of Sapporo, which was first designated in 1975, has been partially changed twice. The present one, which was decided in March 1985, covers an area of 23,449 ha. In this paper, however, we use the data as of 1980, that is, an area of 23,220 ha for urbanization promotion.

The zone along the subway lines means the area within a radius of 750m from the nearest stations of the South-North line or the East-West line, taking the walking distance of people into consideration. (Figure 2)

The data of population density are based on our research made on the areas of blocks within the urbanization promotion area and also based on the population by the block surveyed in 1975, 1980, and 1985.

In principle, the definition of "block" accords with jo-chome streets including alleys. But as for the blocks in the peripheral area of urban area, which usually have larger areas, each block was divided into several smaller blocks to make balance throughout all the blocks. As a result, the whole urbanization promotion area was divided into 7,000 blocks.

The area of each block was measured on a map with a scale of 1/2,500. The population in a block was calculated utilizing the resident registration as of the time when a census was taken, with the cooperation of the General Planning Department of Sapporo City.

The studies so far were made according to rings, which were established based on the past statistical tracts and have irregular intervals with each other. But this time, our data are based on the distance belts which have regular intervals from urban center, in other words, the concentric circle belts.

As for the establishment of the distance belt, we examined 7 cases, that is, a belt with a width of the 100m, 250m, 500m, 750m, 1000m, 1500m, 2000m. In consequence, for the

purpose of macroscopic studies, we determined to utilize the distance belts which are fixed every 750m from belt center line and have a width of 1500m. We decided to use the unit of 750m, giving consideration to the walking distance of the people.

The center point of distance belts was fixed at the point where Odori Park meets at right angles the street stretching from the Sapporo Railway Station.

The population density in the distance belt was expressed by means of a gross density, based on the data of area and population by the block in the area concerned, excluding large building sites with an area of more than 3ha. In order to gain a clear picture of distribution by the distance belts, we used: [1] distribution curves gained by a data-smoothing method, [2] regression lines, [3] regression quadratic curves, [4] probability distribution curves.

2. Change in population and areas in blocks on each density level

2.1 Distribution of population and areas in blocks on each density level

With a rapid increase in population, Sapporo experienced both urban sprawl into suburban areas and a gradual decline in the population density in DID. This section focuses on changes in structure and comprehension by quantity of the density composition in urban areas in 1975, 1980, and 1985.

The six levels of the density are as follows: (0/ha), (0～40 persons/ha), (40～80p/ha), (80～120p/ha), (120～200p/ha), (more than 200p/ha). Population, the composition rate of population and of areas were studied scientifically on each level.

A result of the research shows that during those ten years there was little change in population in the low density blocks on the (0/ha) and (0～40p/ha) levels and in the high density blocks on the (more than 200p/ha) level. On the contrary, there was a population increase on the other three levels, (40～80p/ha), (80～120p/ha), and (120～200p/ha). Among them, the increase on the (80～120p/ha) level was considerable and in every five years a steady increase occurred on this level. The fact indicates that a tendency of concentration on the middle density blocks was taking place. The composition rate of population by year shows this tendency more clearly. (Figure 4～5)

During a formation process of Sapporo City, a tendency of distribution of population was approaching toward middle density blocks. However, from the viewpoint of areas, the middle density blocks on the (80～120p/ha) level accounted for just 19% in 1985, in contrast with a high rate occupied by the low density blocks.

Scrutinizing the tendency in more detail, block areas decreased considerably on the (0～40p/ha) level and increased on the levels of more than 40p/ha. The area increase especially on the (40～80p/ha) and (80～120p/ha) levels was quite big. As seen in the population change, the (80～120p/ha) level showed a steady increase in areas, likewise, in every five years. That is to say, the composition rate of areas also indicates a tendency toward middle density blocks. (Figure 6)

2.2 Distribution of blocks on each increase/decrease level for the densities of population and areas

This section deals with population, the composition rate of population and of areas on each level in blocks which showed an increase or a decrease in the densities during two periods, 1975～1980 and 1980～1985. The observation was conducted on nine levels;(+−0/ha, no-change) and in both increase and decrease,(0～10p/ha),(10～50p/ha),(50～100p/ha),(more than 100p/ha).

The blocks with changes occupied 85% in 1975～1980 and 88% in 1980～1985, respectively, of total urbanization promotion areas. There was no change in only a few blocks, more than 90% of which had no inhabitants. That is to say, the population density was changing in most of the blocks with inhabitants in urbanization promotion area, and the population movement was rapid in urban areas.

During the two periods the rates of changes in both areas and population were bigger in the blocks where the densities increased as compared to the blocks where the densities decreased. However, despite the fact that population increased over the entire urban areas, a number of blocks showed a population decrease. Such blocks accounted for 31% in 1975

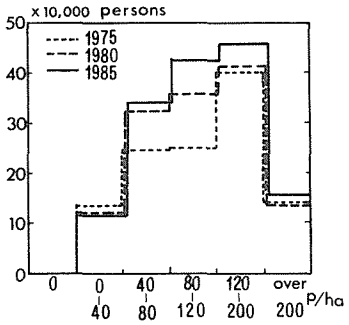


Fig. 4 The number of populations

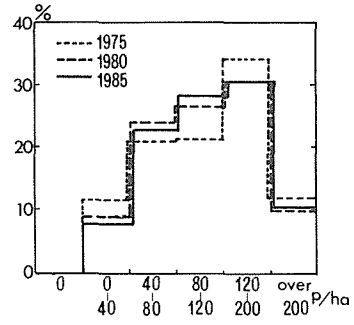


Fig. 5 The rate of populations

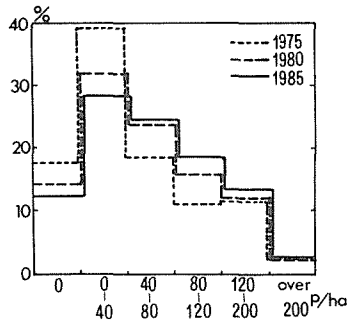


Fig. 6 The rate of areas

Fig. 4, 5, 6 The number of populations and the rate of populations and areas of blocks for each grade of population density − Sapporo, 1975, 1980, 1985

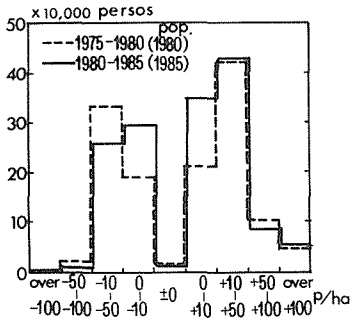


Fig. 7 The number of populations

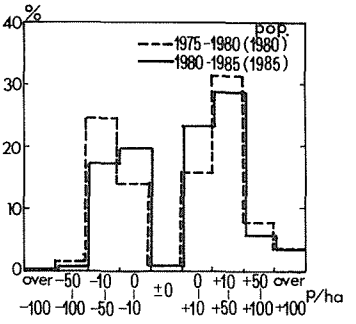


Fig. 8 The rate of populations

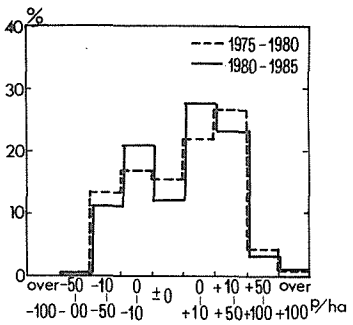


Fig. 9 The rate of areas

Fig. 7, 8, 9 The number of populations and the rate of populations and areas of blocks for each grade of increased or decreaased population density
− Sapporo, 1975～1980, 1980～1985

~1980 and 33% in 1980~1985, respectively, of the total urbanization promotion areas. This is a quite interesting phenomenon which illustrates a rapid movement in population.

Running a comparison between the two periods, the ranges of increase/decrease in both areas and population were, in many blocks, (+−50p/ha). The composition rate of areas and population were low on the (10~50p/ha) and (−10~−50p/ha) levels. In contrast, they were high on the (0~10p/ha) and (0~−10p/ha) levels, and fluctuation in the density was small. (Figure 7~9)

3. Change in the population density in blocks as spatial distribution

3.1 Distribution of blocks on each density level

Change in the composition of the block population density on each density level has been pointed out, and here, we discussed on the condition of spatial distribution of blocks and the tendency of change.

Observing spatial expansion of urbanization and change in population growth in 1975 and 1985, it is clear that change in spatial distribution over the entire urbanization promotion areas during those ten years was extremely large. (Figure 10~11)

Because urbanization promotion area in Sapporo City were set up largely inexpectation of urbanization for ten years, most peripheral areas of urbanization promotion area were occupied by the low density blocks on the (0~40p/ha) level. However, in 1985 the density increased in the low density blocks and thus the blocks on the (0~40p/ha) level became few in number. Urbanization in the peripheral areas made remarkable progress during those ten years.

The high density blocks on the (more than 200p/ha) level showed little change in the composition rate of areas in urbanization promotion area. The spatial distribution of the high density blocks showed a tendency of dispersion from the surrounding areas of the central business and shopping district toward the peripheral areas.

3.2 Distribution of blocks on each density increase/decrease level

Referring to spatial distribution on each density level and focusing on the blocks where the density increased in 1975~1980 and 1980~1985, it was seem that the blocks of the increased density were distributed in the central area, contrary to a general idea that a doughnut phenomenon was in progress in the central area. In 1980~1985, especially, the tendency become more noticeable. The blocks of the increased density which were found mostly in the peripheral areas, were distributed all over the urban area. (Figure12~13)

On the other hand, the blocks of the decreased density were found in the peripheral areas in the process of urbanization, and were increasing in rate. This is just in contrast with a tendency of block distribution of the increased density. (Figure14~15)

Putting together spatial distribution of blocks on the increased and decreased density, it is interesting to note a tendency of mosaic-like mixture of blocks on the increased or decreased density all over the urban area.

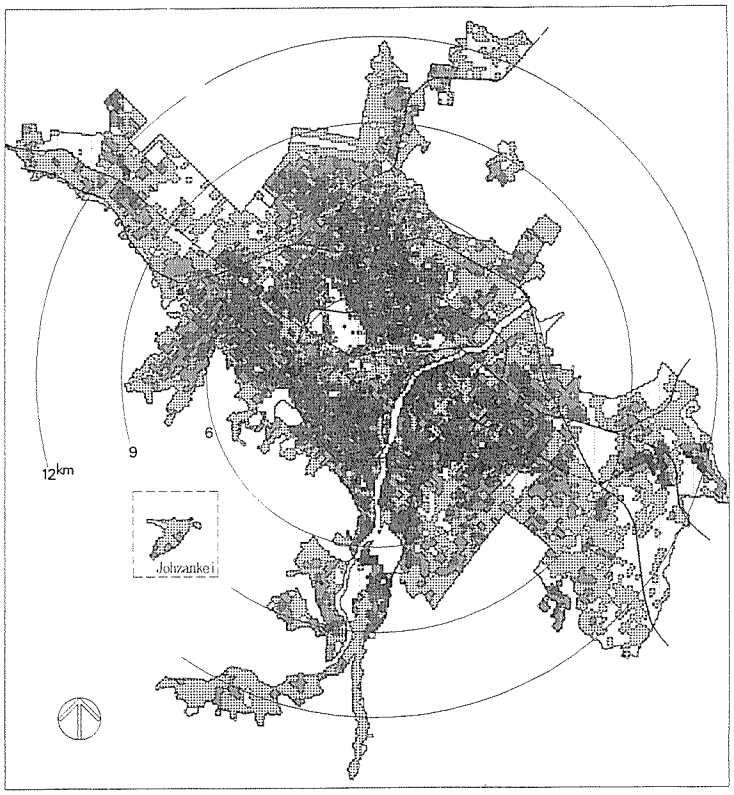


Fig. 10
The distribution of the population densities in U. P. Area Sapporo, 1975

population density
- 0 persons/ha
- less than 40 p/ha
- over 40~less than 80
- over 80~less than 120
- over 120~less than 200
- over 200 p/ha

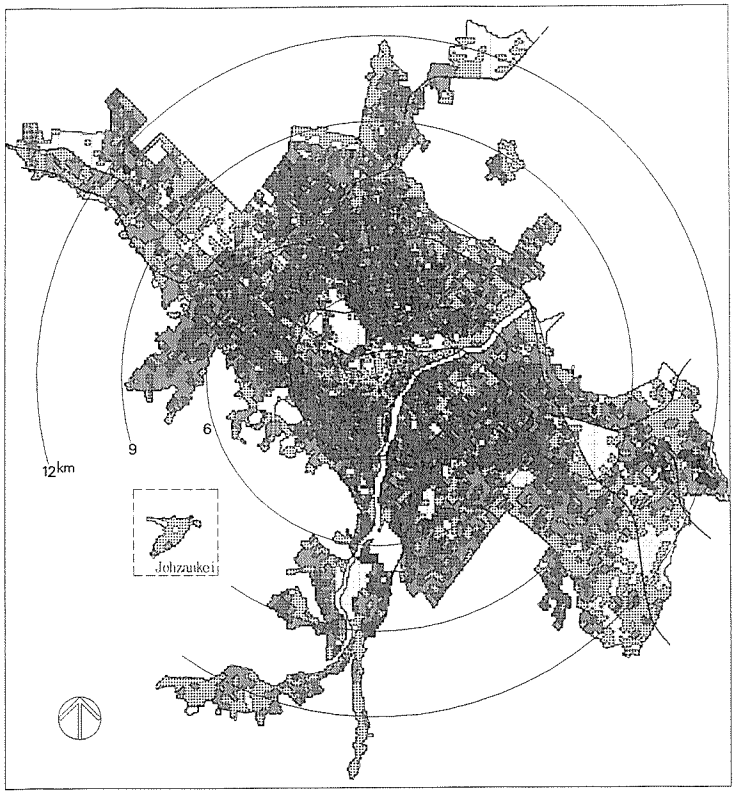
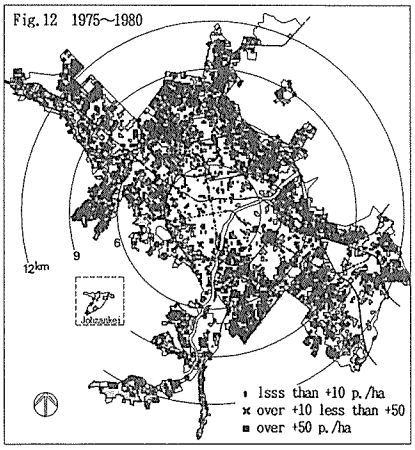


Fig. 11
The distribution of the population densities in U. P. Area Sapporo, 1985

population density
- 0 persons/ha
- less than 40 p/ha
- over 40~less than 80
- over 80~less than 120
- over 120~less than 200
- over 200 p/ha



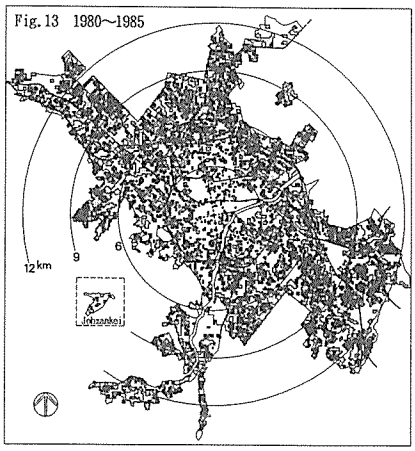
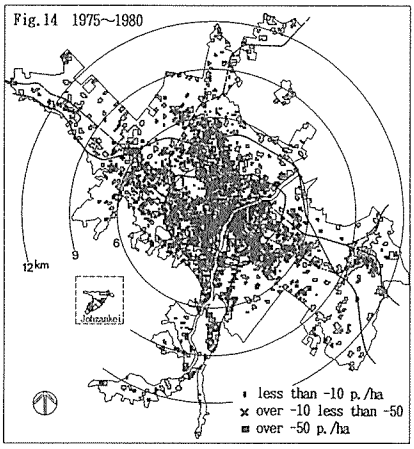


Fig. 12, 13 The distribution of the population density increased blocks in U. P. Area — Sapporo, 1975~1980, 1980~1985



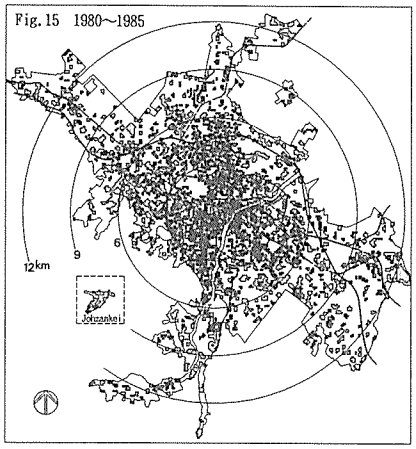


Fig. 14, 15 The distribution of the population density decreased blocks in U. P. Area — Sapporo, 1975~1980, 1980~1985

4. Population density distribution in the distance belt and the tendency of density change in urbanization promotion area

4.1 Population density distribution in the distance belt

A detailed study was made on the relations between population density and distance from urban center, based on the density by the block within the urbanization promotion area in 1975, 1980 and 1985.

As a result, we found that the densities in these three years were expressed, without exception, as a curve shaped like a mountain. In other words, there is a common tendency that the density is the highest in the area within a radius of 1.5 to 3 km from urban center, the peak being 110 to 120 p/ha in terms of a gross density. (Figure 16)

Comparing the states of density distribution in 1975, 1980 and 1985, we find that the density in the peripheral area of urban area have been on the increase, although the position of the culmination is more or less the same. We also found that the tendency of distribution changes at the point of 3km from urban center, that is, the density is on the decrease within a radius of 3km and is on the increase beyond 3km. (Figure 16)

In this way, the relations between population density and distance from urban center, which once were grasped in terms of distribution by rings, can be clearly understood by means of the distance belt which is set at regular intervals based on the detailed data.

Because the distribution curve is rather gentle, the distance can be measured, for convenience, in terms of a straight line. In the urban area where the density curve falls toward the periphery, it is notable that the gradient of the expression for this curve changes at the point of 7.5 to 9km from urban center, the boundary of DID in 1975. (Expression 5～10)

The change of the gradient in the area mentioned above reflects the fact that the urban area has experienced various stages of formation in the course of the development of Sapporo City.

In this paper, an attempt is also made to understand the relations between the density distribution ranging from urban center to the periphery of urban area and the distance from the urban center by means of the numerical expressions.

As for the expressions of this kind, there are well-known exponential functional

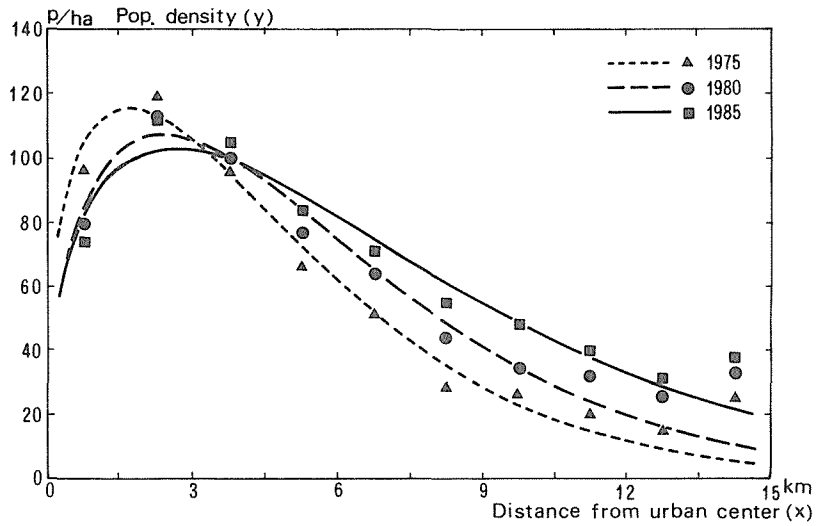


Fig. 16 The population densities for each concentric circle belts in U. P. Area and wiebull distribution curves – Sapporo, 1975, 1980, 1985

	1.5～9km from urban center	7.5～13.5km from urban center
1975 :	$y=-15.10x+151.6$ $(r=0.992)$ ···(5)	$y=-3.07x+54.8$ $(r=0.966)$ ···(6)
1980 :	$y=-11.69x+141.0$ $(r=0.990)$ ···(7)	$y=-3.63x+72.1$ $(r=0.951)$ ···(8)
1985 :	$y=-9.86x+137.2$ $(r=0.982)$ ···(9)	$y=-5.31x+99.3$ $(r=0.993)$ ···(10)

expressions elaborated by Colin Clark and Newling. Although the one by Colin Clark is the most famous, it is not sufficient to express a doughnut phenomenon and to explain the contemporary urbanization. We examined the probability distribution expressions by Poisson and Weibull, which have not been paid much attention so far, but could not obtain good results except Weibull expression.

A study utilizing Weibull expression was once made by Taguchi (1976).[4] In that case, he employed a maximum likelihood method of Weibull probability distribution function, and did not obtain good results out of the data on Sapporo. We, therefore, decided to use a line regression method utilizing Weibull cumulative distribution function, which is commonly applied to data analysis of reliability of products in terms of their breakdowns and lifespans.

The functional expressions and the estimate expression of the parameters are as follows.

$$y = A \cdot f(x) \tag{1}$$

$$f(x) = (p/\theta)\, x^{p-1} \mathrm{Exp}(-x/\theta) \tag{2}$$

$$F(x) = 1 - \mathrm{Exp}(-x^p/\theta) \tag{3}$$

When (3) is applied to a logarithmic expression, we obtain ;

$$\mathrm{Ln\ Ln}\left\{\frac{1}{1-F(x)}\right\} = p\ \mathrm{Ln}(x) - \mathrm{Ln}(\theta) \tag{4}$$

f (x) : a relative value of population density by Weibull probability distribution function.

F (x) : a relative cumulative value of density by Weibull cumulative distribution function.

y : population density in the distance belt

x : distance from urban center

p, θ : parameters

A : a coefficient for transforming the relative value of density into the absolute value.

Consequently, regarding the three points of time, we gained an expression which produces about 0.99 of correlation coefficient between the data and estimate values. These correlation coefficients is rather higher than the ones we gained before by other expression. The parameter values and correlation coefficients are as shown below. (Table 3)

Table 3

year	p	θ	A	r
1975	1.3177	8.3658	792.44	0.992
1980	1.3864	12.0548	888.40	0.988
1985	1.3312	14.3658	1046.73	0.987

Weibull distribution expression has a high degree of adaptability to a distribution without a doughnut phenomenon.

We conclude that Weibull function is quite superior as an expression to grasp the relationship between density distribution and distance, in that it has good adaptability to our data on population density distribution and is useful in a wider application.

When we applied this function to the data of other cities with higher population density, we obtained good results, too. In addition to the densities distribution, we also found high adaptability of Weibull expression to population and areas distributions by the density level. These points will be reported later on.

4.2 Tendency of densities change in the distance belt

As for the increase of the density in the distance belt during the ten years from 1975 to 1985, the number of increase is the greatest in the area at a distance of 7.5 to 9km from urban center. It is the circumferential area of DID in 1975, where the relations between density distribution and distance change. Namely, the greater the distance from urban center is, the greater the number of increase is inside the circumference, and vice versa outside the circumference. (Figure 17)

As for the increase rate on the other hand, the farther a place is from urban center, the higher the rate is. The rate is especially high in urban area beyond 7.5km from urban center. (Figure 18)

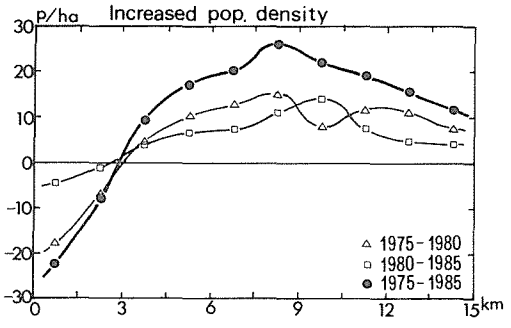


Fig. 17 The amount of pop. densities increase

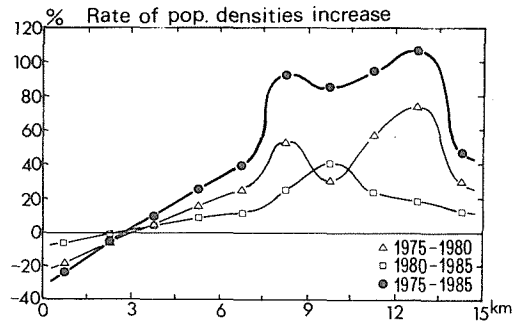


Fig. 18 The rate of pop. densities increase

Fig. 17, 18 The population densities increase for each concentric circle belts in U. P. Area — Sapporo, 1975~1980, 1980~1985, 1975~1985

When we look at the change of density in every 5 years (1975~1980 and 1980~1985), we find that the pace of increase is slow both in terms of the number and rate in the density increasing area which is 3 to 9km distance from urban center.

As a new tendency of the last 5 years, we can recognize that the pace of decrease has become much slower in the density decreasing area which is within 3km from urban center. It is interesting that this tendency is particularly notable in the central business and shopping district within 1.5km from urban center. In this area, the rate of decrease has been lowered remarkably ; from 1975 to 1980, the rate of decrease was 18p/ha, and from 1980 to 1985 it was 4p/ha. A relatively high level of density, 75p/ha, has been maintained in this area as of 1985.

5 Distribution of blocks with the increased/decreased population density in view of the relations to the distance from urban center

5.1 Distribution of blocks with the increased/decreased population density in each distance belt

As the spatial distribution figure showed, the blocks with the increased/ decreased population density were distributed all over the urban area. There seemed to be a relationship between a tendency of the blocks distribution and the distance from urban center.

Blocks distribution in each distance belt from urban center was examined to make the relationship clear. Among the blocks with the increased density, the peak was at the (4.5～7.5km) belt, and among the blocks with the decreased density, the (1.5～3km) belt. Both of the blocks were on a straight decline inwardly and outwardly from their peaks. (Figure 19)

From the viewpoint of the composition rate, in the areas within 9km from urban center which used to be DID until 1975, the blocks with the increased density and the blocks with the decreased density were respectively distributed in a X-shape straight linefasion going from and toward the urban center. (Figure 20, Expression 11～14)

Comparing the tendency in 1975～1980 and that in 1980～1985, both had the similar straight lines. However, it should be mentioned that in 1980～1985 a mixture of increase and decrease was noticeably in progress. To put it specifically, in the central urban area within 4.5km from urban center, a tendency of increase was on the increase and a tendency of decrease was on the decrease ; on the contrary, in the (4.5～9km) belt a tendency of increase was on the decrease and a tendency of decrease was on the increase.

5.2 Mixture degree of increase/decrease in the density by entropy

In order to grasp a mixture condition in the increased/decreased population density blocks, consecutive distribution of blocks with (increase, 0, decrease) in a block density in every 100m distance belt was made out. The consecutive distribution confirmed a mixture condition of blocks from the viewpoint of the density movement. (Figure 21)

Then, in order to grasp mixture as an index, entropy (H) in place of a mixture condition was used in the expression below, based on emergence probability of blocks with increase, decrease, or no－change in each distance belt.

$$H = -\Sigma\ Pi \cdot Log(Pi) \qquad (15)$$

$$Pi = \frac{nbti}{NBT} \qquad (16)$$

NBT : total numbers of blocks within a distance belt
nbti : numbers of blocks on increase, decrease, no-change

As the result, in 1975～1980, in urban areas within 7.5km from urban center which were DID in 1975 and in areas which were urbanized after 1975, the relations to the distance from urban center were grasped as a repetition of two quadratic curves, which were side by side,

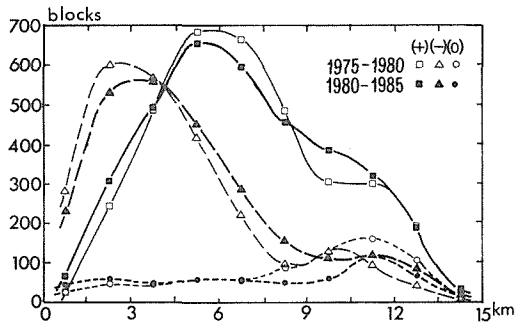


Fig. 19 The number of blocks

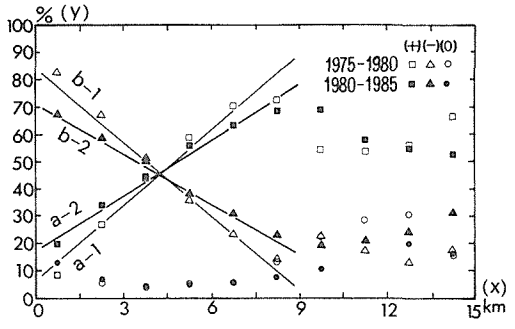


Fig. 20 The rate of block numbers

Fig. 19, 20 The blocks distribution for each concentric circle belts of increase, decrease, no-change of population densities — Sapporo, 1975～1980, 1980～1985

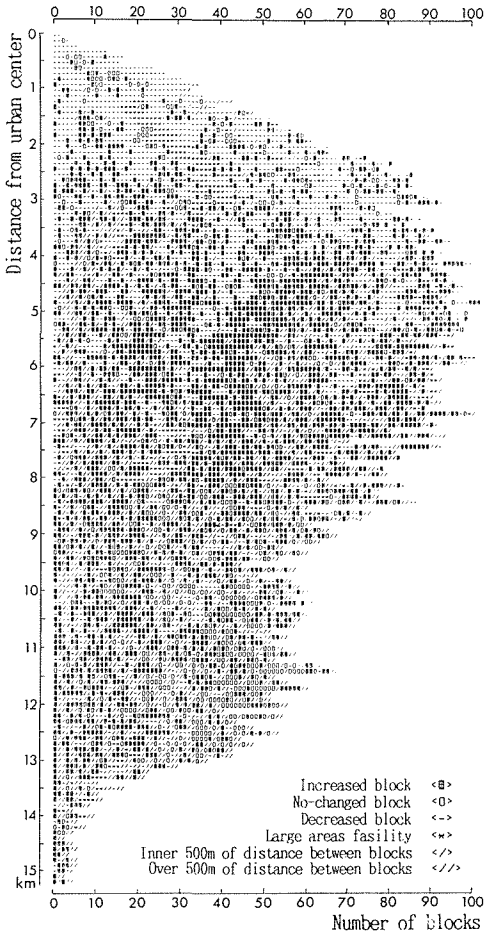


Fig. 21 The blocks distribution sequence in concentric circle belts (100m) of increase, decrease, no-change if population densities — Sapporo, 1975～1980

a－1 : (1975—1980 ; Increase)
$y=8.87x+7.2$ $(r=0.957)$ ⋯(11)

a－2 : (1980—1985 ; Increase)
$y=6.57x+18.4$ $(r=0.976)$ ⋯(12)

b－1 : (1975—1980 ; Decrease)
$y=-9.31x+87.6$ $(r=0.993)$ ⋯(13)

b－2 : (1980—1985 ; Decrease)
$y=-6.25x+72.7$ $(r=0.994)$ ⋯(14)

(By data inner 9 km from urban center)

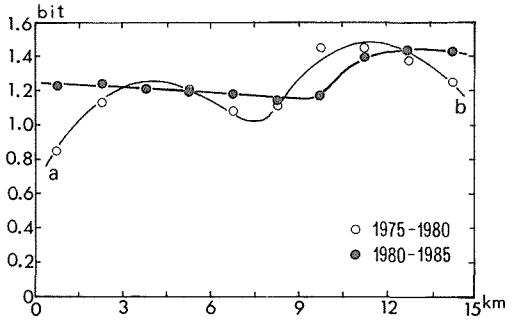


Fig. 22 The entropy by probability of the blocks distribution in concentric circle belts (1.5km) of increase, decrease, no－change of population densities — Sapporo, 1975～1980, 1980～1985

a : (0—7.5km) $y=-0.0343x+0.282x+0.66$⋯(17)
$(r=0.996)$

b : (7.5—15km) $y=-0.0305x+0.699x-2.54$⋯(18)
$(r=0.940)$

with different coefficients ; the peaks of two curves were at the (3～4.5km) belt where the blocks with increase/decrease were distributed at the same rate, and the (10.5～12km) belt. However, in 1980～1985 mixture of blocks with increase/decrease advanced and entropy became high in the central business district and around DID in 1975 where entropy was relatively low. In areas within 10.5km, regardless of the distance, entropys showed nearly equal values. (Figure 22, Expression 17～18)

It was found that a brisk movement of the density in urban areas was closely related to change in the distance relation of entropy which was as a mixture degree.

Compared with DID in 1975, peripheral urban areas, which had mixture of the new and old districts in, such as Teine, Fujino and Eastern areas, showed high entropy and reflected a real condition accurately.

Mixture degree would be possibly used as another index to grasp degree of change, mobility, stability and instability which indicate a population increase/decrease in areas.

6. Population density distribution in each distance belt within and outside the subway line areas and the changing tendency in population density

6.1 Population and the changing tendency in population density in the subway line areas

Difference in population distributions in various distance belts in all the urbanization promotion area has been studied. Findings indicate that the population is distributed not only according to the concentric circle like distance belts but also varies in radiating forms according to the infrastructure such as subways, railways or trunk roads.

For the further study, the subways are taken up to see the population and the density distribution as well as their change.

The subway is a significant means of transportation in such a city like Sapporo with a cold climate and heavy snowfall and its construction had been a matter of great concern for quite a long time. The final nomination to host for the 1972 Winter Olympic Games led the way to the drafting of the subway system in 1976. Its aim was to alleviate the traffic congestion caused by the snow and cold and to shorten the travel time for those living in the urban areas. Today there are two lines, South-North and East-West, with 32 stations. Another line, Toho line, is now under construction. (Table 2)

The outside of the subway line areas are studied as well and a comparison was run, together with the urbanization promotion area.

It is natural that the subway line areas are quite densely populated since they have been developed as urban areas with a fair size of population. As of 1985, the average population density of these areas was 99p/ha, which was 1.4 times as that of the urbanization promotion area (70p/ha). When compared with that of the outside of the subway line areas (64p/ha), it was about 1.6 times as large, with a difference of 35p/ha.

The population of the subway line areas was 360,000 in 1975, 361,000 in 1980, and 380,000 in 1985. Over the past decade, it increased by approximately 6%. However, compared

with the average increase observed in the urbanization promotion area which was 28%, it was only its 1/4 and still low. When viewed in terms of change in its share in the overall population of Sapporo, it was 31% in 1975, 27% in 1980, and 25% in 1985. There is a clear indication of decline.

As for the rate of population increase if viewed for every five years between 1975 and 1985, it was observed as slowing down in the urbanization promotion area whereas in the subway line areas it gained on the contrary.

6.2 Population density distribution in the distance belts in the subway line areas

Population density distribution was studied according to the distance belts in the subway line areas as had been for the urbanization promotion area.

Our findings show that in the distance belt within 3km from urban center, which was a fully developed area with subway line areas occupying much of the land area (89% within 1.5km and 45% within 1.5~3km), population densities distribution was much the same as that of the overall urban area. However, in the distance belt within 3~6 km, it remained much the same still (about 120p/ha in 1985). This indicates that the distance from urban center did not affect the high population density within the distance belt of 1.5~6km. (Figure 23)

When contrasted to the observation of the population density of the overall urban area that declined steadily, this can be regarded as a unique characteristic of this specific distance belt.

This particular tendency observed in the subway line areas is an interesting phenomenon to be noted, for it served to push up the population density in the less congested areas of the urban area to the level of the circumference of the central business district and thus can be surmised that the population absorbing effect of the subway has caused a deviation in the relationship, which is generally observed in the urban area, between the population density and the distance from urban center.

6.3 Population density distribution in the distance belts outside the subway line areas

As for the urban area outside the subway line areas, in the distance belts of the outside area within 1.5km, the population density was still high, although it was adjacent to the central business district. This can be accounted for by the old urban area located in the southwest with the high density blocks, of more than 200p/ha, which was not yet eroded by the commercial function. Thus, the densities distribution by the distance belts in the outside of the subway line areas did not show a doughnut phenomenon as did in the general observation of the urbanization promotion area. Rather there was a constant decline in population density from urban center toward the periphery. (Figure 24)

6.4 Changing tendency in population density in distance belts

The change in population density in different distance belts in and outside the subway line areas when looked every five years from 1975 to 1985 was such that the distance belt close to the center within 3~4.5km had seen a greater increase in the subway line areas than outside. However, in the distance belts further away from urban center, the increase

became less than outside. (Figure 25)

From 1980 to 1985, population density increased in the subway line areas in the distance belt within 1.5~7.5km more than its outside areas. Also it was observed that in both the subway line areas and outside within this distance belt the increase became larger toward the peripheral. (Figure 26)

The changing tendency in population density as seen every five years from 1975 to 1985 indicates that the population absorbing effect of the subway was not a phenomenon simultaneously emerging throughout the subway line areas immediately after its operation. Rather it showed itself gradually with the passing of time.

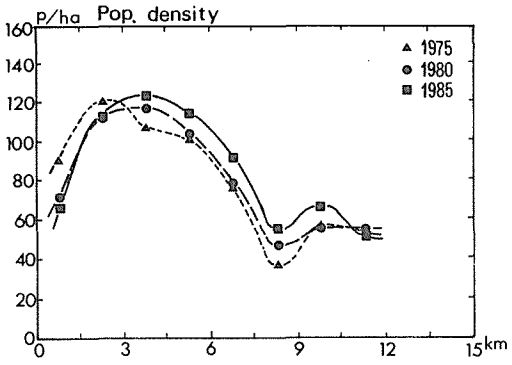


Fig. 23 In the subway belt

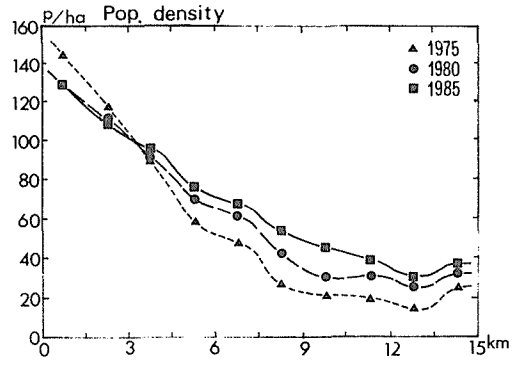


Fig. 24 In outside area of the subwaybelt

Fig. 23, 24 The population densities for each concentric circle belts in the subway belt and it's outside area — Sapporo, 1975, 1980, 1985

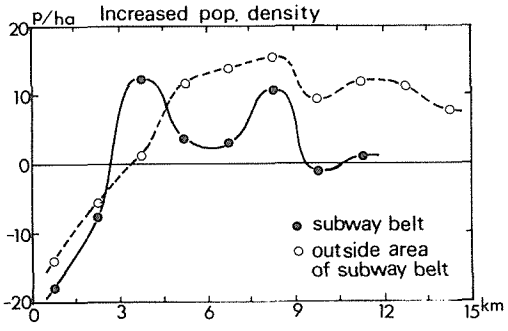


Fig. 25 1975~1980

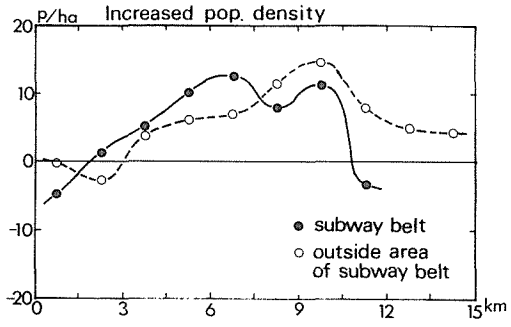


Fig. 26 1980~1985

Fig. 25, 26 The amout of the population densities increase for each concentric circle belts in the subway belt and it's outside area — Sapporo, 1975~1980, 1980~1985

7. Conclusion

In this paper, the population density distribution and its changing tendency on the basis of blocks over the recent past decade in a rapidly city, Sapporo, were studied.

Weibull probability distribution function, a probability function between the population density distribution in the urban area and the distance from urban center, has shown not only the actual correlation between the two but also an emerging doughnut phenomenon. Also the use of a relational expression which is more precise and widely applicable has yielded fruitful findings.

Weibull probability distribution function has been recognized as applicable to other big cities. It will be reported on another occasion.

Furthermore, the shifting population density caused by the rapid growth of population was successfully observed by the entropy in reference to the increase or decrease of density and their co-existing phenomenon.

Such a population densities distribution and its changing tendency enabled the author and his staff to approach the subject matter on the basis of the distance from urban center and see the gradually regressing doughnut phnomenon in the central business district, the formation of the belt area with the highest density that had shown little change, and such an inclination in some other areas that had been marked by the decreasing density but were then regarded as reversely increasing.

The findings can be interpreted as an appearance of the following four areas ; (1) the central business district where the doughnut phenomenon is fading, (2) its adjacent urban area with a high but stable density, (3) the area that had been already developed as an urban area by 1975 but is again gaining its population although it is physically located along the steadily decreasing line of population density from urban center, and (4) a new developing area in the peripheral of the urban area where a rapid urbanization process since 1975 is now producing higher density.

On the other hand, urban function such as the subway that can affect the population distribution have indeed brought about a change ; ie a change into a radial pattern rather than a concentric circle like pattern. Thus the population density distribution in the subway line areas deviated much from the generally observed pattern in the overall urban area and had produced a new wide distance belt of high population density, conflicting with the general correlation between the population density and the distance from urban center. Such a unique phenomenon in terms of the urban space structure could be closely studied with ample statistics. This study will provide important suggestions to the drafting and development of the future infrastructure in regards to the urban space structure that may greatly affect the population distribution of the city, such as a construction of another subway line or the establishment of additional stations along the JR' railway in Sapporo.

Future studies will need to include the effects of large unused spaces still left in the urban area and large-scale facilities. A comprehensive analysis to cover such other land use, commercial and business functions, and economic indexes as the land price will be also necessary. Some analysis has been made already on this, but a close analysis is now carried out.

This paper has discussed on the concentric pattern of population density distribution

but at the same time has observed that there are also other possible strong factors such as the subway line that are likely to induce alternate patterns. Different routes may show another pattern. All those only indicate that further studies based on block units must be carried out with a general examination on the radial distribution pattern, which has been so far dealt with from statistical block units.

The analysis on the actual condition of Sapporo has clearly demonstrated the correlation between the change in the population density as well as its distribution and the distance from urban center. It is quite significant that this study now provides some meaningful clues to the estimation of the future population growth and to the analysis of the urban space structure.

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