Population Densities by Distance from the Center of City and their Change over 1965 to 1970 in Japanese Selected Cities

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It is well known that population density varies with distance from the center of city. Clark (1951, 58) examined this generalization empirically by applying the following equation: $D_x=Doe^{-bx}$
where D_x is the population density at distance x from the center of city, Do is the population density at the city center, e is the base of the natural logarithms, and b is the density gradient which is a natural logarithm measuring the rate of change of density with distance. This function is transformed linearly into $ln\ D_x=ln\ Do-bx$.

So far, empirical application of this equation has been made by Stewart (1958), Berry (1963) and Newling (1966) *etc.* Also, applicability of this equation to Japanese principal cities was tested by the author (1973), using the 1965 population census data. However, because of unavailability of data, the cities with the DID population between 300,000 and 1,000,000, or the four local major cities were excluded from the examination.

In this paper, the changes in density gradient, central density and applicability of this model over 1965 to 1970 are examined for each sector of Tokyo as well as for other cities, in addition to the test for the cities having the DID population between 300,000 and 1,000,000, on the basis of 1970 census data.

1 Applicability of the Model to the Four Local Major Cities and Other Cities Based on 1970 Census Data

As mentioned above, because of lack of the data based on grid squares for the four local major cities, Sapporo, Fukuoka, Hiroshima and Sendai, all of which had the DID population of 300,000 to 1,000,000 and were located outside the metropolitan areas of Tokyo, Osaka and Nagoya, the application of the model was not done for these cities in the previous examination. So, by using the 1970 population census data for the census tracts which were delineated within the city with 300,000 or more inhabitants or with the prefectural office, having the average population of 10,000 respectively, the equation mentioned above was applied to these cities. The methodology used is as follows:

(1) The center of city and its census tract were decided, at first.

(2) On the map showing the census tract boundaries, eight radial routes to

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east, west, south, north, northeast, southeast, southwest and northwest, in general, were drawn from the city center.

(3) Basing upon the population density of the census tract which was located each one kilometer starting upto the periphery of DID/ from the center of city, parameters of the equation $ln\ D_x = ln\ Do - bx$ were obtained.

(4) At the same time, the correlation coefficient r between $ln\ D_x$ and x was calculated.

Thus, the values of b, Do and r for the four local principal cities are shown in Table 1. According to this table, the correlation coefficients ranging from *-0.61* to *-0.78* indicate a moderate goodness of fit for the equations in those cities.

By the similar way basing on the 1970 population census data for one square kilometer grid squares, the equation was applied to other eleven cities, Tokyo, Yokohama, Gifu, Chiba, Utsunomiya, Hachioji, Kofu, Maebashi, Toyama, Nagano and Mito, all of which were located in Kanto and Chubu regions. The values of b, Do and r, also, are presented in Table 1.

Based on the density gradients b and the size of DID population y for the above 15 cities, the following two types of equations were derived by least square method:

$$y = 3684 - 5308\,b, \text{ and } ln\,y = Y = 7.9163 - 4.0744\,b$$

The correlation coefficient showed *-0.6036* for the former and *-0.8201* for the latter.

Table 1 Values of parameters and correlation coefficient in the equation of Clark's model, and size of DID population for 15 cities, 1970

City	N	Do	b	r	DID pop. (thousand)
Tokyo	151	15,810	0.085	−0.45	8,793
Yokohama	54	11,200	0.088	−0.12*	1,935
Sapporo	57	17,033	0.364	−0.61	803
Fukuoka	41	14,033	0.230	−0.59	712
Hiroshima	39	18,546	0.352	−0.71	497
Sendai	47	18,717	0.540	−0.78	433
Chiba	31	13,005	0.629	−0.44	313
Gifu	41	20,275	0.559	−0.80	264
Utsunomiya	41	10,512	0.641	−0.74	175
Hachioji	41	22,137	0.773	−0.64	165
Kofu	41	21,504	1.020	−0.65	136
Maebashi	41	10,031	0.527	−0.79	121
Toyama	41	10,132	0.636	−0.71	121
Nagano	41	6,093	0.660	−0.45	120
Mito	41	7,018	0.542	−0.75	92

Note: N refers to the number of samples in which density and distance were measured. r refers to the correlation coefficient between $ln\ D_x$ and x in the equation.

* shows no significant correlation at a level of 0.05.

The both were significant at a level of 0.05. This means that there exists high association, in particular, close relation in exponential function, between the size of DID population and the density gradient as already found in another set of 15 cities based on the 1965 census data.

2 Changes of Density Gradient, Central Density, and Applicability of the Model over 1965 to 1970 in Each Sector in Tokyo

Calculating the correlation coefficient between variables in the equation $lnDx=lnDo-bx$, for overall routes of north, east, west, northeast, southwest and northwest from the center of city in Tokyo, it presented *–0.54* for 1965 and *–0.43* for 1970. This implies overall fitness to the model reduced in 1970. Computing the correlation coefficient for each of the routes separately, a high goodness of fit for the equation was found in the four routes of north and northwest, northeast and southwest for 1965, on the other hand it was seen in only two routes of north and northeast and no significant association was recognized for the routes of east, west and southwest; particularly, in 1970, rare fitness for west route was found as the correlation coefficient being *–0.03* and not significant.

Comparing the absolute values of the correlation coefficients between 1965 and 1970, they reduced in four routes, but increased in northeast route and kept the same value in north route. These findings imply that applicability of Clark's model reduced in each sector excluding northeastern and northern sectors in Tokyo in 1970 compared with 1965.

Comparison of the density gradient between 1965 and 1970 for each route from the city center in Tokyo gives that the density gradient decreased in every routes in 1970. This means that population distribution within the city extended outward. Among the density gradients of the six routes west route presented the greatest decrease (980%) while north route indicated the smallest (38%).

Table 2 Values of parameters and correlation coefficient in the equation of Clark's model for each radial route from the center in Tokyo, 1965 and 1970

Route	*Do*		*b*		*r*	
	1970	1965	1970	1965	1970	1965
North	10,717	22,560	0.108	0.149	−0.76	−0.76
West	6,873	10,535	0.004	0.042	−0.03*	−0.37*
East	5,895	16,650	0.074	0.146	−0.26*	−0.39
Northeast	23,792	52,950	0.102	0.192	−0.67	−0.58
Southwest	10,930	19,045	0.064	0.168	−0.37*	−0.53
Northwest	13,941	24,750	0.063	0.107	−0.46	−0.67

Note: r refers to the correlation coefficient between $ln\ D_x$ and x in the equation.
* shows no significant correlation at a level of 0.05.

Also, comparison of the imaginal densities at the city center derived from the model showed a decline between 1965 and 1970 for each route of the six routes in Tokyo. For eastern and western sectors, particularly, the imaginal central densities were under 10,000 persons per square kilometer in 1970, although they had been over 10,000 persons per square kilometer in 1965 for all the sectors. Needless to say, this is owing to notable dispersion of population from the city center to the outskirt.

Assuming the marginal population density of substantive urbanized area, i.e., DID as 4,000 persons per square kilometer, the imaginal location indicating the marginal density, or the distance of the place with the density of 4,000 persons per square kilometer from the center of city is obtained by using the equation derived for each route from the center in Tokyo, as shown in Fig. 1. Connecting the each point presenting the marginal density in the each route, an irregular polygon can be drawn. This depicts a simplified spatial figuration of DID. Comparison of this figurations for certain time intervals gives a simple measurement for degree of spatial expansion of a DID.

Average distance from the city center to the marginal density, 4,000 persons per square kilometer, which was derived from the equation for the overall routes in Tokyo, was 12.4 km in 1965, and it extended to 16.3 km in 1970. Observing Fig. 1, in 1965, the periphery of DID in western route showed the longest distance (23.4 km) from the center, while that in southwestern route presented the shortest distance (9.3 km). The margins of DID in other routes were located in the range from 9.8 km to 17.1 km. In 1970, the periphery for overall routes elongated, as described above; particularly, the edge in western route shifted to the distance of 145.0 km from the center. In other routes the location indicating the marginal density moved outward in the distances of 12.9 km to 20.1 km. The smallest extension was seen in northern route. From these findings it can be inferred that during the period from 1965 to 1970 the DID or urban built-up area in Tokyo expanded, in particular, greatly westward.

Observing the change in actual population density over 1965 to 1970 at the point each one kilometer along each radial route from the center in Tokyo, it is known that, generally speaking, the population densities at the center and its vicinity declined remarkably, while the densities in distance of about 10 km to 20 km from the center increased. It is obvious that such changes in actual density affected reduction of applicability of Clark's model for Tokyo. Also, along west route considerable rise in density which was observed in particular in wide range of the outskirt influenced the remarkable elongation of density gradient and the notable reduction of degree of fitness to the model for west route. (Fig. 2)

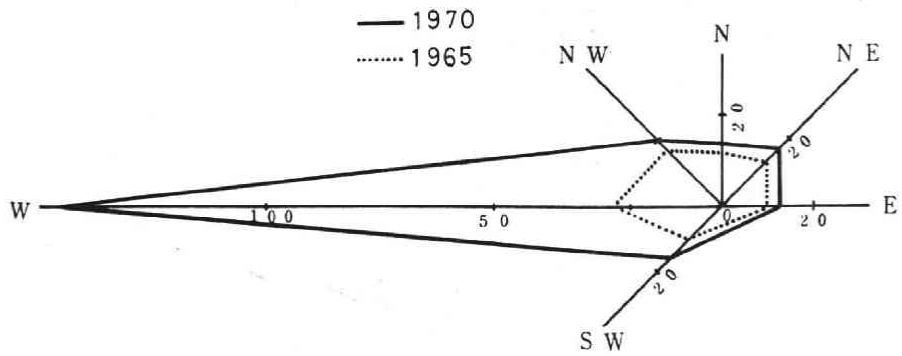

Fig. 1 Location indicating the density of 4000 persons/km² by radial routes from the center of city unit: km 0: center of city

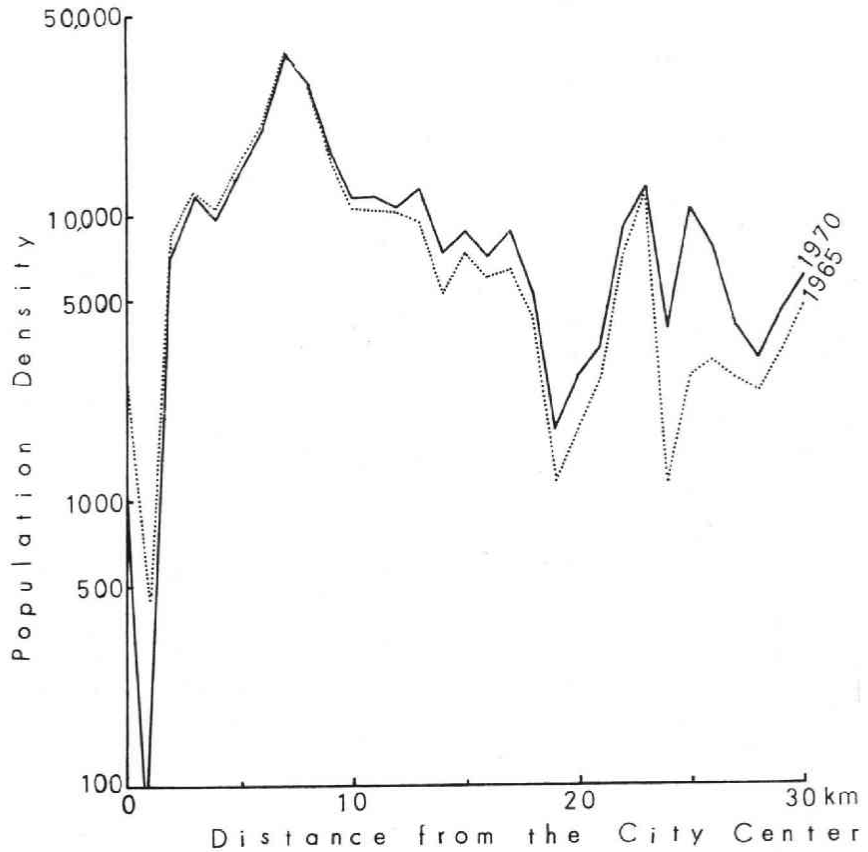

Fig. 2 Population densities (persons/km²) by distance from the city center for western routes in Tokyo, 1965 and 1970

3 Changes of Density Gradient, Central Density and Applicability of the Model over 1965 to 1970 in the Selected Cities

For the cities of Tokyo, Yokohama, Gifu, Chiba, Utsunomiya, Hachioji and Kofu, comparison of density gradients which were derived from the single equation of the model for each city as a whole for respective years between 1965 and 1970 reveals a decrease in density gradient for each city. This may be an evidence of the regularlity that the density gradient declines with passage of time as already pointed out by Clark (1951, 58) and Newling (1966).

Table 3 Comparison of values of parameters and correlation coefficient in the equation of Clark's model for the selected cities between 1965 and 1970

City	*Do*		*b*		*r*	
	1970	1965	1970	1965	1970	1965
Tokyo	15,810	24,045	0.085	0.146	−0.43	−0.52
Yokohama	11,200	10,300	0.088	0.149	−0.12*	−0.22*
Gifu	20,275	19,615	0.559	0.576	−0.80	−0.80
Chiba	13,005	15,655	0.629	0.881	−0.44	−0.54
Utsunomiya	10,512	17,350	0.641	1.069	−0.74	−0.61
Hachioji	22,137	25,600	0.773	1.209	−0.64	−0.69
Kofu	21,504	27,690	1.020	1.122	−0.65	−0.78

Note: r refers to the correlation coefficient between $ln\ D_x$ and x in the equation.
* shows no significant correlation at a level of 0.05.

On the other hand, the central densities between 1965 and 1970 for those cities show the increase for Yokohama and Gifu and the decrease for other cities. Chatterjee suggested the regularity that the central density increases with passage of time, then decreases in Western cities, while it increases continuously in non-Western cities (Berry and Horton 1970). However, the above finding does not give applicability of this regularity to Japanese cities.

Observation of the correlation coefficients calculated on the equation, $ln\ D_x = ln\ Do - bx$, between $ln\ Do$ and x for each city 1965 and 1970 gives reduction of degree of fitness to the model for the cities except Utsunomiya as the correlation coefficients decrease in absolute values.

Actually it is difficult to make generalization on changes in parameters of the model and its applicability based on these observations, because the number of cities observed is small. However, it can be inferred that in Japanese cities the density gradient decreases with passage of time.

Conclusion

Based on the 1970 population census data, applicability of Clark's model that the population density declines in the form of exponential function with distance

from the city center was examined and was assured for the four local major cities, Sapporo, Fukuoka, Hiroshima and Sendai, as well as for the 11 cities in Kanto and Chubu regions. Also, high association between the density gradient and size of DID population was found for those cities.

Combining the results based on the 1965 census data which was reported previously with this finding (Otomo 1973), it can be said generally that the population distribution within the cities with at least 100,000 inhabitants in Japan follows Clark's model.

In Tokyo, the locations indicating the marginal density of DID, 4,000 persons per square kilometer, which were obtained from the equations derived from the model, shifted outward along the six radial routes, in particular, westward from the city center, during the period from 1965 to 1970. However, the degree of fitness to the model reduced for each route except for northeast and north routes, and no significant relation was found for the three routes in 1970.

From the comparison of the density gradients, central densities and correlation coefficients between the variables in the equation of the model for the seven selected cities between 1965 and 1970, declining tendency of density gradient and reduction of the degree of fitness to the model can be concluded, but no conclusion for the central density is drawn.

Acknowledgement must be made by the author to Prof. Toshio Noh who has guided him in his study, and to Prof. Kasuke Nishimura who gave him the opportunity to publish this paper. Also, the author expresses his gratitude to Dr. Norio Hasegawa who has encouraged him to continue his study and to Dr. Setsuo Ogasawara who helped him to draw the figure in this paper.

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