PROC. OF JSCE,
No. 237, MAY 1975

REGIONAL STRUCTURE OF CITY-REGION BASED ON COMMUTING AND SCHOOL ATTENDING TRIPS

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1. PREFACE

With the great advance of economic structures, the city-ward tendency of population has been a conspicuous matter. In the past 50 years, the the urban population has increased rapidly from 18% to 72% of the total population in Japan. This tendency causes such serious social problems as a densely populated phenomenon in cities and a sparsely populated phenomenon in local regions.

However, we know that the city has a central function for its outlying area in politics, economy, culture and other fields. In short, the city has become the nucleus of a certain unified areas (rural-urban community) in which the closest contact with the suburban arears has been maintained. Consequently not only the increase of the settled population (concentration of population) but the day-time population (centralization of population) promotes the growth of the city, and the commuters and the persons attending school coming from the suburban areas constitute the main cause of the increase of the day-time population. As the commuters and the persons attending school between the city and its outlying area during rush hours are a one-way traffic current, there are many important problems concerning the traffic planning.

In order to solve these problems, it is necessary for the traffic planners to clarify the phenomena of commuters and persons attending school which are the daily movement from one area to another. Therefore, it is very important, from the viewpoint of traffic planning, to grasp quantitatively the relations between the characteristics of the city-region that is taken as an index to these traffic current, and the traffic pattern connecting closely the city and its outlying area.

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The aim of this paper is to make a general hypothesis through analyzing the structures of the city-region in terms of traffic planning. Thus, it is necessary to collect many accurate data in various regions.

The author has taken note of the data in census, and has analyzed the conditions of flowing of commuters and persons attending school in terms of population and the shortest time distance. The studied areas selected for the application of the proposed theory are 123 cities (which include all the cities with more than 100,000 population in Japan).

2. THE CONCEPT OF CITY-REGION

(1) The Definition of City-Region

As we have not a definite technical term for the regional sphere which involves the central city and its outlying area, the author has used the term "city-region" following Dickinson, R. E.[1]

If the area which is formed with a city as a center is called the city-region, it is the regional sphere which is under the direct influence of the central city. The extent of the city-region is determined by the functions of the central city, the areal structures of its outlying area, and other various factors which are connected each other. Also, the boundary of the city-region can not be lined clearly, because it often duplicates and interferes intricately.

The researches on the city-region range over various fields, which can be classified into the following three types;

① The field of Agricultural Sociology. (since 1910)

The Rurban Community by Galpin, C. J.[2] and others.

② The field of Urban Sociology. (since 1920)

The Metropolitan Community by Park, R. E.[3], Mckenzie, R. D.[4] and others belonging to the

Chicago school from the human ecological point of view.

③ The field of Urban Geography. (since 1930) *The Hierarchy of Central Place* by Christaller, W.[5], Lösch, A.[6] and others.

Moreover, in a broader sense, the theories of the Megalopolis by Gottmann, J.[7], the Ecumenopolis and the Dynapolis by Doxiadis, C. A.[8] and so on refer to the city-region.

In Japan, many researchers are engaged in their studies about the city-region in the fields of sociology and geography.

(2) The Hypothesis of City-Region

The city-region is a regional sphere in which the various functions of a central city influence upon its outlying area. In other words, it is a compound consisting of several kinds of zones. As the meaning and substance of the compound have never been consistent in definitions, we can not classify the city-region properly.

We should try to grasp both quantitatively and qualitatively how the functions of a central city exert the influences on its outlying area. For this purpose, we need to take into consideration the following four factors;

The core (the center)
The outlying area
The boundary (the limit)
The object of investigation

The boundary establishes a regional sphere of the city-region clearly. There are two types of boundaries. One is the natural surroundings and the other is the distance away from the center. In these days of well-developed traffic facilities, the former is only a minor problem while the latter has become the important factor.

As for the boundary of distance (traffic limit), Ogawa, H.[9] has classified it into three kinds. They are the theoretical limit, the absolute limit and the relative limit. In these limits, the relative limit is quoted from the researches of Arisue, T.[10] The theoretical limit is represented by the sphere in which P/M value is equal to zero on the P/M curve. (The P/M curve and the P/M value are denoted in the next chapter.) The absolute limit is represented by the sphere in which the inflowing traffic volume numbers over 1. And at the outside of this, it is zero. Lastly, the relative limit is determined by the number of passengers by the flowing direction of them at railway stations or bus stops and so on (see Reference 10)).

In this paper, the author has viewed that the closest mutual contact between a central city and its outlying area can be grasped by the commuters and the persons attending school traffic current, and has supposed the city-region with the sphere of these trips.

3. THE MEASUREMENT OF THE HYPOTHESIS OF CITY-REGION

(1) Distribution Model for the Traffic of Commuters and Persons Attending School

The gravity model, the basis of which is in Newton's law of gravitation, has generally been used as a model of traffic distribution. For the first time, Carey, H. C.[11] applied this principle to a social phenomenon, and it was further established by Stewart, J. Q.[12], Zipf, G. K.[13], Isard, W.[14] and others[15].

However adaptability is extremely bad, when trip length becomes short or long. Therefore, in the present analysis, the P/M curve[16], which is a kind of gravity model suggested by Ogawa, H., is used.

We suppose an originating railway station as station i and a destination as station j $(j=1, 2, \cdots, m)$. The station j is set in the numerical order according to the distance from the station i. P_{ij} is the number of passengers from the station i to the station j, and M_j is the total number of the passengers getting off at the station j (includes P_{ij}). If we plot travel time (R_{ij}) required from the station i to the station j on the horizontal axis and the P_{ij}/M_j value on the vertical axis, we may obtain a hyperbolic curve for this graph, because the traffic volume is apt to decrease in proportion to the increase of travel time. Then, this curve was named the P/M curve by Ogawa, H., and he verified its phenomenon in Kamaishi City district. The P/M curve can be denoted with the following equation;

$$P/M=a/R-b \qquad (a>0,\ b>0) \quad \cdots\cdots\cdots (1)$$

where a and b are the coefficients and are obtained by least-squares method. Moreover this equation can be obtained by the gravity model as follows;

Now, suppose we define a central city as area i and its outlying area as area j $(j=1, 2, \cdots, m)$. The gravity model is expressed by,

$$P_{ij}=a'(P_iP_j)^{\beta}/(R_{ij})^{n} \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (2)$$

where

P_{ij}: the inflowing traffic volume from area j to area i.
P_i, P_j : the population of area i and area j.
R_{ij}: the distance between area i and area j.

n, β, a': the exponents and a coefficient.

If β is equal to 1. Equation (2) is

$$P_{ij}/P_iP_j = a'/(R_{ij})^n \quad \cdots\cdots (3)$$

P_i is a constant at each area j. Moreover, we know that there is a positive correlation between P_j and M_j. Thus, if we replace M_j by P_j.

$$P/M = P_{ij}/P_j$$

Finally, equation (2) is expressed as follows;

$$\begin{aligned} P/M &= a'P_i/(R_{ij})^n \\ &= A/(R_{ij})^n \quad \cdots\cdots (4) \end{aligned}$$

Such trip as the commuters and the persons attending school is a cyclic return trip in a day. Consequently, if we represent the R_{ij} by the shortest time distance, the P/M value must be equal to zero at a certain trip distance (t_2). Applying this concept to equation (4), we can express equation (4) as follows;

$$P/M = a/R^n - b \qquad (a>0,\ b>0) \quad \cdots\cdots (5)$$

The theoretical limit of trips is defined by the distance, when the P/M value in equation (5) is zero. We can calculate this value as follow;

$$t_2 = \sqrt[n]{b/a} \quad \cdots\cdots (6)$$

The P/M curve is shown in Fig. 1.

(2) The Establishment of City-Region[17]

With the combination of the proposed traffic distribution model and the theoretical limit, we can establish the city-region of a central city. As shown in Fig. 1, we can see distinctly that the inflowing traffic volume from outlying area is apt to decrease by an exponential curve in proportion to the increase in time distance, and to sharply decrease to at certain time distance from a central city. It is the most remarkable feature. So we may well establish city-region on the basis of this phenomenon. Then, the author assumes that the limit of the city-region is indicated by the regional sphere, in which travellers get conscious of the trip time, and defines this as the Primary Limit of trips (t_1).

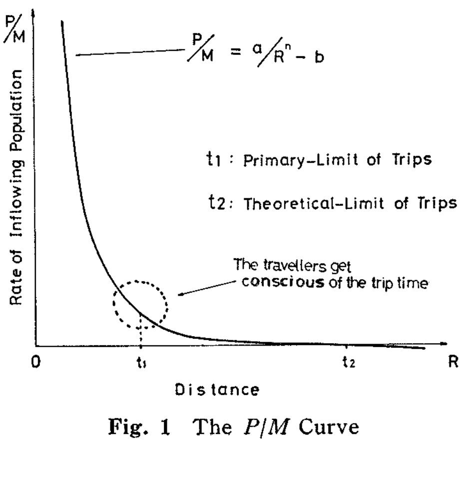

Fig. 1 The P/M Curve

The pattern of traffic current of the commuters and the persons attending school seems to be changed by this limit. So in this paper, the boundary of the city-region is determined by this limit. We can apply the idea of the curvature to analyze this traffic limit. The author defines as the boundary point that takes a minimum value of the radius of curvature at Fig. 1, and represents this point as the primary limit. We can simply calculate this point, if we put

$$P/M \fallingdotseq f(R)$$

$$d(P/M)/dR = f'(R) \qquad d^2(P/M)/dR^2 = f''(R)$$

The radius of curvature (ρ) is shown by the following formula;

$$\rho = (\sqrt{1+(f'(R))^2}\,)^3 / f''(R) \quad \cdots\cdots (7)$$

Therefore, the primary limit can be obtained by equation (8).

$$\left.\begin{aligned} t_1 &= R_{\min\rho} \\ &= \sqrt{a} \end{aligned}\right\} \quad \cdots\cdots (8)$$

4. AN EMPIRICAL EXAMINATION OF THE HYPOTHESIS OF CITY-REGION

We know well that one of the most important things in regional analysis is how to collect materials. That is, the materials for this analysis must be correct and be obtained from many areas. For this purpose, the census figures are the most useful data. Then in this analysis, the materials are taken from the Population Census[18] of Japan in 1965 (October of Showa 40th), and 123 cities have been selected. These cities are all cities in Japan with 100,000 to 1,000,000 population.

(1) The Application of a Traffic Distribution Model

We suppose the commuters and the persons attending school make railway available as far as their destination and some of them ride in a bus where there is no railway. And we estimate equation (5) with the following hypotheses;

Hypothesis 1

As for commuters and persons attending school to area i, we define as the inflowing population the people whose places of work and schooling are in the city in question, but whose usual places of residence are in other cities, towns and villages (area j) at 1965 Population Census

Table 1 Table of

City		P / M Curve						Population of City-Region[2] (1000 persons)	Coefficient of Inflow[3]
No.	Name	Coefficient of Centrality (a-value)	Primary Limit (min.)	Theoretical Limit (min.)	Correlation Coefficient: Method ①	Method ②: Cor. Coef.	Method ②: n [1]		
1	Sapporo	3111.9	56	144	0.9381	0.9428	1.375	302.7	4.87
2	Asahikawa	3838.1	62	96	0.7714	0.8198	0.675	159.9	7.42
3	Otaru	1370.2	37	107	0.7933	0.9011	3.475	26.2	0.34
4	Hakodate	4791.7	71	137	0.9224	0.9250	1.400	93.1	5.68
5	Muroran	4202.0	65	101	0.9311	0.9795	2.925	65.5	7.04
6	Kushiro	1587.5	40	162	0.8452	0.8549	0.325	26.0	4.27
7	Obihiro	1408.2	38	128	0.9116	0.9120	1.100	71.0	5.51
8	Aomori	3484.5	59	114	0.8224	0.8675	3.000	59.0	3.93
9	Hirosaki	1234.2	35	187	0.8548	0.8961	0.300	145.9	3.10
10	Hachinohe	2526.2	50	123	0.8047	0.8073	1.875	41.7	6.92
11	Morioka	2529.7	50	131	0.9182	0.9165	1.350	101.7	5.05
12	Sendai	4496.1	67	153	0.9237	0.9242	0.950	376.6	8.31
13	Akita	5059.1	71	139	0.8169	0.8486	0.750	148.1	7.80
14	Yamagata	2404.3	49	160	0.9351	0.9379	0.850	188.4	4.71
15	Fukushima	2773.6	53	93	0.9161	0.9136	1.525	204.4	4.57
16	Aizuwakamatsu	1533.9	39	164	0.8201	0.8279	0.475	145.0	4.63
17	Koriyama	923.9	30	160	0.8878	0.8895	0.925	110.3	3.74
18	Mito	1442.9	38	191	0.8104	0.8429	0.700	219.9	4.00
19	Hitachi	1767.1	42	127	0.8465	0.8539	1.275	151.7	2.88
20	Utsunomiya	1183.6	34	175	0.6452	0.6700	0.500	269.5	2.60
21	Ashikaga	475.1	22	99	0.7367	0.7365	1.025	156.8	1.65
22	Maebashi	1537.2	39	83	0.8348	0.8410	1.650	302.8	2.14
23	Takasaki	1098.7	33	101	0.8129	0.8207	1.350	283.1	2.17
24	Kiryu	1424.5	38	100	0.8723	0.8668	1.075	236.6	3.45
25	Kawagoe	681.2	26	83	0.3712	0.4479	0.300	211.2	0.65
26	Kumagaya	591.8	24	143	0.6150	0.6422	0.700	175.8	1.11
27	Kawaguchi	299.5	17	124	0.7056	0.6987	1.075	159.4	0.57
28	Urawa	343.9	19	194	0.8305	0.8481	0.625	51.7	0.58
29	Omiya	526.9	23	99	0.5663	0.7166	0.375	215.2	0.54
30	Chiba	1557.1	39	145	0.7688	0.7750	0.725	255.1	0.88
31	Ichikawa	364.0	19	151	0.7799	0.7586	1.350	0	0.51
32	Funabashi	298.9	17	94	0.7850	0.7967	0.900	89.9	0.33
33	Matsudo	327.3	18	125	0.5557	0.5632	1.550	0	0.31
34	Kashiwa	481.6	22	67	0.8703	0.8878	0.925	113.8	0.26
35	Hachioji	638.7	25	120	0.5537	0.5892	0.525	91.5	0.70
36	Tachikawa	430.4	21	190	0.5323	0.6724	0.175	263.6	1.27
37	Musashino	336.8	18	122	0.7943	0.8252	0.225	138.3	0.71
38	Mitaka	505.6	17	79	0.7704	0.8408	0.150	0	0.45
39	Fuchu	249.8	16	176	0.7455	0.7575	0.600	37.7	0.64
40	Chofu	238.2	15	79	0.8782	0.8794	1.525	40.0	0.52
41	Machida	171.2	13	107	0.8613	0.8675	0.825	0	0.41
42	Kodaira	134.1	12	70	0.7384	0.7769	0.375	74.9	0.50
43	Yokosuka	861.3	29	130	0.6986	0.6971	1.100	43.2	0.48
44	Kawasaki	684.1	26	140	0.5969	0.5948	1.025	0	0.89
45	Hiratsuka	722.1	27	138	0.8036	0.8175	0.725	40.3	1.09
46	Kamakura	237.7	15	65	0.8474	0.8738	0.725	0	0.61
47	Fujisawa	515.3	23	166	0.8187	0.8277	0.500	10.1	0.68
48	Odawara	1849.0	36	107	0.6599	0.6777	0.750	49.1	1.08
49	Chigasaki	172.8	13	82	0.5657	0.5867	0.775	16.2	0.28
50	Sagamihara	892.2	30	104	0.5719	0.5651	2.350	70.3	0.69
51	Niigata	2059.5	45	135	0.8875	0.9145	0.675	316.3	6.13
52	Nagaoka	1845.0	43	100	0.8730	0.9140	1.900	201.2	3.90
53	Toyama	2274.5	48	161	0.7608	0.7692	0.625	530.3	6.00
54	Takaoka	1386.6	37	75	0.6960	0.7920	0.225	244.9	3.06
55	Kanagawa	2858.9	53	137	0.6979	0.7444	0.175	430.5	4.86
56	Fukui	1972.2	44	100	0.8287	0.8734	0.400	262.5	9.32
57	Kofu	1771.5	42	176	0.7908	0.8734	0.300	211.8	5.16
58	Nagano	2920.3	54	89	0.8175	0.8682	0.550	384.0	4.64
59	Matsumoto	3446.5	59	174	0.8343	0.8694	0.400	208.2	3.88
60	Gifu	1124.9	34	99	0.5525	0.6300	0.425	343.6	1.60
61	Ogaki	799.7	28	156	0.6289	0.6372	0.900	131.3	1.72
62	Shizuoka	921.6	30	191	0.8010	0.8408	0.550	380.1	2.81

Notes: (1) It is represented with an exponent n which takes a minimum value of x^2-value at equation (9).
(2) It is represented with the amount of resident population within the sphere of primary-limit of trips
(3) The Coefficient of Inflow = Inflowing population / Outflowing population.
Inflowing population shows the total of those whose places of work and schooling are in the city in
Outflowing population shows the total of whose usual places of residence are in the city in question,

Hypothesis of City-Region

City		P / M Curve						Population of City-Region[2] (1000 persons)	Coefficient of Inflow[3]
No.	Name	Coefficient of Centrality (a-value)	Primary Limit (min.)	Theoretical Limit (min.)	Correlation Coefficient: Method ①	Correlation Coefficient: Method ② Cor. Coef.	Method ② n[1]		
63	Hamamatsu	1 820.1	43	198	0.7644	0.7954	0.575	363.4	2.53
64	Numazu	1 009.8	32	92	0.7769	0.7984	0.750	149.4	2.24
65	Shimizu	906.4	30	87	0.8339	0.8382	1.375	47.2	1.27
66	Toyohashi	866.2	29	127	0.8048	0.8008	1.100	242.6	1.62
67	Okazaki	427.5	21	151	0.6232	0.6111	0.425	17.5	0.63
68	Ichinomiya	220.8	15	69	0.6692	0.6761	0.750	78.1	0.92
69	Kasugai	130.1	11	160	0.5804	0.4731	0.025	0	0.29
70	Toyota	1 794.9	42	88	0.8725	0.8879	1.625	188.9	1.83
71	Tsu	1 294.3	36	123	0.8022	0.8178	0.825	208.7	1.90
72	Yokkaichi	1 521.4	39	148	0.8470	0.8529	0.875	422.9	2.14
73	Ise	1 096.5	33	155	0.9273	0.9271	0.900	94.3	1.24
74	Suzuka	425.7	21	169	0.5862	0.5806	1.225	0	0.40
75	Otsu	1 354.5	37	148	0.8124	0.8118	0.800	143.7	1.35
76	Sakai	956.9	31	119	0.6218	0.6090	1.125	271.9	0.65
77	Kishiwada	149.8	12	77	0.8199	0.8837	0.375	69.4	0.40
78	Toyonaka	299.5	17	127	0.7939	0.7958	1.125	187.6	0.30
79	Suita	173.5	13	189	0.8687	0.8817	1.150	43.4	0.52
80	Takatsuki	232.8	15	77	0.9126	0.9226	1.525	52.1	0.52
81	Moriguchi	166.3	13	128	0.8597	0.8597	1.000	95.2	0.68
82	Hirakata	320.0	18	86	0.6058	0.5954	1.325	0	0.36
83	Ibaragi	164.6	13	118	0.5851	0.6094	0.800	174.2	0.74
84	Yao	259.9	16	126	0.8476	0.8317	0.800	45.0	0.48
85	Neyagawa	128.7	11	109	0.8296	0.8184	1.125	0	0.37
86	Himeji	3 838.6	62	171	0.6753	0.6832	0.625	441.3	2.47
87	Amagasaki	471.1	22	120	0.7929	0.8452	1.775	328.3	0.59
88	Akashi	841.9	29	142	0.5367	0.5771	1.475	10.0	0.59
89	Nishinomiya	174.9	13	120	0.8337	0.8297	1.050	154.7	0.45
90	Itami	335.4	18	72	0.4325	0.4439	0.825	61.3	0.51
91	Kakogawa	680.8	26	148	0.6483	0.6464	1.200	84.5	0.66
92	Nara	640.1	25	116	0.6676	0.7505	0.425	212.5	0.79
93	Wakayama	1 625.1	40	131	0.8486	0.8291	0.525	369.8	1.98
94	Tottori	1 729.6	42	113	0.7087	0.8011	0.425	91.2	8.19
95	Matsue	1 630.2	40	105	0.7115	0.7525	0.550	230.6	5.61
96	Okayama	2 838.4	53	121	0.7211	0.7919	0.175	488.5	7.40
97	Kurashiki	1 357.4	37	111	0.6120	0.6280	0.600	83.0	1.85
98	Hiroshima	6 530.0	81	152	0.8179	0.8327	0.500	783.3	4.36
99	Kure	2 270.2	48	157	0.5531	0.5506	1.225	175.6	1.10
100	Fukuyama	1 314.1	36	148	0.6918	0.6927	1.100	146.1	3.91
101	Shimonoseki	2 805.0	53	167	0.5437	0.6031	0.300	129.6	0.17
102	Ube	1 071.3	33	96	0.6650	0.6896	0.700	84.4	2.78
103	Iwakuni	1 544.8	39	86	0.5958	0.5833	0.250	100.4	1.86
104	Tokushima	2 241.2	47	132	0.8292	0.8423	0.700	228.9	3.99
105	Takamatsu	3 813.1	62	174	0.8203	0.8317	0.875	249.1	9.11
106	Matsuyama	3 416.6	58	146	0.8976	0.9265	0.650	141.9	6.53
107	Imabari	3 610.1	60	91	0.8501	0.8432	1.450	109.2	5.17
108	Niihama	686.4	26	189	0.7045	0.7204	0.850	52.4	2.94
109	Kochi	3 289.8	57	171	0.9276	0.9238	1.150	203.4	4.69
110	Fukuoka	5 524.8	74	139	0.8618	0.8496	1.150	1397.6	7.39
111	Kurume	1 564.3	40	69	0.7402	0.7863	0.600	276.3	3.20
112	Omuta	731.5	27	136	0.9074	0.9219	0.750	95.9	2.48
113	Saga	1 813.7	43	156	0.8429	0.8411	1.175	324.7	6.20
114	Nagasaki	5 374.8	73	124	0.8957	0.8777	1.300	173.0	5.50
115	Sasebo	2 387.4	49	135	0.6169	0.6173	1.050	51.9	2.22
116	Kumamoto	2 175.7	47	102	0.7483	0.8013	0.450	279.6	6.99
117	Yatsushiro	811.7	28	136	0.8608	0.8649	0.950	22.6	2.60
118	Oita	2 607.4	51	188	0.7555	0.7662	0.725	191.7	3.81
119	Beppu	1 329.9	36	106	0.8901	0.9479	2.375	20.1	0.92
120	Miyazaki	1 836.5	43	151	0.9338	0.9370	0.950	96.9	5.68
121	Miyakonojo	742.4	27	135	0.8529	0.8697	0.850	88.2	3.53
122	Nobeoka	2 444.9	49	120	0.8978	0.8999	1.575	76.8	2.81
123	Kagoshima	3 371.9	58	176	0.8995	0.9102	0.725	259.0	7.46

(excluding the population of the central city).

question, but whose usual places of residence are in other cities, towns and villages.
but whose places of work and schooling are in the other cities, towns and villages.

of Japan. Thus, the P/M values in equation (5) are described with the ratio of the inflowing population (P_{ij}) from area j to area i to by the population (P_j) of area j, and this is named the rate of inflowing population.

Moreover, the population (P_j) is shown in thousands and the inflowing population (P_{ij}) is shown in a person.

Hypothesis 2

As for the necessary time to commute and to attend school, we take the shortest travel time between the administrative center of a central city and its outlying area which was divided into cities, towns and villages. Then, we represent the distance (R_{ij}) in equation (5) with that, and access time to railway stations or bus stops is not taken account of here.

Hypothesis 3

The commuters and the persons attending school make their trips from 7:00 to 9:00 am.

To apply equation (5), the following two methods were used.

① If we assume that the exponent n is equal to 1, as a simple model, becomes the P/M curve. The calculated result is shown Table 1.

② As we have three unknown quantities in equation (5), we can not calculate directly with the least-squares method. Then, with 400 least-squares solutions which change n value from -0.025 to -10.000, first an exponent n is determined by n value which takes a minimum value of χ^2 value as follows;

$$\chi^2=\sum_{j}^{m} [(P'_{ij}-P_{ij})^2/P_{ij}] \quad \cdots\cdots\cdots\cdots (9)$$

where

P'_{ij}: the estimated quantity of inflowing population from area j to area i. (person)

P_{ij}: the actual quantity of inflowing population from area j to area i. (person)

Thereafter we can obtain coefficients a, b by using a given n value immediately.

By the result of practical solution, method ② takes too much calculating time and a correlation coefficient, which shows the goodness of fit of model, is of almost the same value as method ①. (Table 1) So it is more convenient to utilize method ①, which is easier to calculate.

In addition, the coefficient a in equation (5) shows a positive correlation with the indices (shown in Table 5) which show the conditions of concentration of city functions, and with the coefficient of inflow (shown in Table 1, and this value denotes the centralization of trips), and

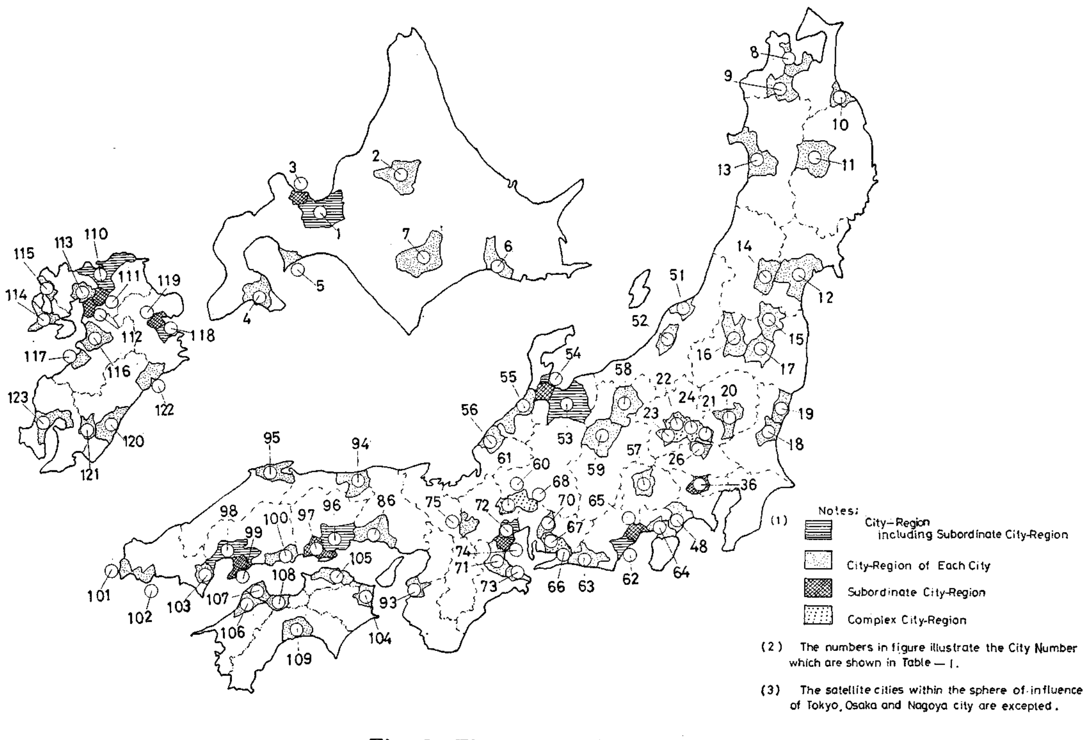

Fig. 2 The Figure of City-Region

with the population of city-region (shown in Table 1). Namely, this value represents the degree of the centrality of city, judging from the tendency of the centralization of commuters and persons attending school.

(2) The Hypothesis of City-Region

We must define the regional sphere for the hypothesis of city-region. Then, we take note of the primary limit. The inflowing population from the primary limit of 123 cities varies in quantity, but occupies some 60% of their commuters and persons attending school. We should be satisfied with the limit if we interpret the city-region in a narrow sense.

The city-regions of 123 cities are hypothesized with the equation (8) and are shown in Fig. 2. The primary limits vary according to each city, but are approximately situated in the sphere within an hour time distance.

5. THE ANALYSES OF THE STRUCTURES OF CITY-REGION

We know well that this sort of study has been done by urban sociologists and geographers, such as Burgess, E. W.[19], Ullman, E.[20], Hoyt, H.[21], Dickinson, R. E.[22] and others[23]. These studies are discussed on structures themselves. However we should consider the city-region as the nodal region that includes both a central city and its outlying area and other neighbouring city-regions. In order to accomplish this purpose, we express both regions with its scale and analyze its mechanism qualitatively and quantitatively.

(1) The Qualitative Analysis of the Structures of City-Region

There are various kinds of features in a city. For instance, if we take two cities with the same population, i.e., a central city in the provincial area and a satellite city inside the metropolitan area, we know that the former is far more centralized. Therefore, in order to grasp areal interdependence between the characteristics of the central city and the structures of its city-region, we need to classify the city into some groups. The cities are composed of exceedingly multifarious factors, the mentioned above, their fundamental structures and component factors can not be recognized clearly. In such cases, we may use the factor analysis[24] as an effective method.

Table 2 Eigen Value and the Rate of Cumulative Explanation

Component	Eigen value	Rate of explanatory power	Cumulative percentage
First	15.272	54.5%	54.5%
Second	4.953	17.7	72.2
Third	1.774	6.4	78.6
Fourth	1.196	4.2	82.8
Fifth	0.872	3.2	86.0
Sixth	0.770	2.7	88.7
Seventh	0.684	2.4	91.1
Eighth	0.470	1.7	92.8
Ninth	0.374	1.4	94.2
Tenth	0.295	1.3	95.2

The author follows in this paper the principal component analysis[25] (power method) including 28 fundamental indices which are considered to illustrate various phenomena of the growth of city. These indices are shown in Table 5. The result of the analyses is explainable up to 95.2% of the whole with ten components, and four components take eigen value over 1.0. (Table 2) Especially the rate of explanatory power with the first three components reaches 78.6% of the whole.

According to the factor loading of each index, we find that the first component illustrates the scale of the city or the concentration of city functions, and the second component illustrates the degree in which this will develop into the satellite city and finally the third component illustrates the industrial structure. (Table 3)

For an attempt to classify the cities according to these components, the author tries to grasp quantitatively the degree of possession of each component in each city, and pays attention to the component score (F1, F2) of the first and

Table 3 Factor Loading owing to Principal Component Analysis

First component		Second component		Third component	
Index	Factor loading	Index	Factor loading	Index	Factor loading
X_{10}	0.97349	X_{28}	0.87236	X_4	0.54298
X_{18}	0.96910	X_{26}	0.85081	X_5	−0.82810
X_{15}	0.96696	X_6	0.80005		
X_{22}	0.96316	X_4	0.63963		
X_{17}	0.95956	X_7	0.61426		
X_{12}	0.95097	X_3	−0.72266		
Scale, concentration of the city functions		Degree of showing the tendency of the satellite city		Industrial structure	

Note: Index number is shown in Table 5.

Table 4 A Classification of Cities Based on Principal Component Analysis

First component (F_1)	Second component (F_2)	Classification (Type)	Number of cities (City)	Name of cities	Coefficient of inflow	Coefficient of centrality (a-value)
$F_1 \geqq 1$	$F_2 \geqq 1$	I	5	Chiba, Kawasaki, Sakai, Amagasaki, Nishinomiya	0.69	767.7
	$-1<F_2<1$	II	8	Yokosuka, Gifu, Hamamatsu, Himeji, Okayama, Hiroshima, Fukuoka, Wakayama	3.45	3027.9
	$F_2 \leqq -1$	III	16	Sapporo, Asahikawa, Hakodate, Sendai, Akita, Utsunomiya, Niigata, Toyama, Kanazawa, Shimonoseki, Takamatsu, Matsuyama, Kochi, Nagasaki, Kumamoto, Kagoshima	6.00	3419.9
$-1<F_1<1$	$F_2 \geqq 1$	IV	7	Urawa, Omiya, Ichikawa, Funabashi, Hachioji, Ichinomiya, Toyonaka	0.55	384.7
	$-1<F_2<1$	V	14	Mito, Maebashi, Takasaki, Fukui, Kofu, Numazu, Shimizu, Toyohashi, Yokkaichi, Nara, Kure, Fukuyama, Tokushima, Kurume	3.00	1501.2
	$F_2 \leqq -1$	VI	14	Otaru, Kushiro, Aomori, Hachinohe, Morioka, Yamagata, Fukushima, Koriyama, Nagaoka, Nagano, Shizuoka, Sasebo, Oita, Miyazaki	3.98	2245.9
$F_1 \leqq -1$	$F_2 \geqq 1$	VII	22	Kawaguchi, Matsudo, Tachikawa, Musashino, Mitaka, Fuchu, Chofu, Machida, Kodaira, Kamakura, Fujisawa, Chigasaki, Sagamihara, Suita, Takatsuki, Moriguchi, Ibaragi, Yao, Neyagawa, Akashi, Itami, Hirakata	0.53	324.3
	$-1<F_2<1$	VIII	19	Muroran, Hitachi, Ashikaga, Kiryu, Kawagoe, Kashiwa, Hiratsuka, Odawara, Takaoka, Ogaki, Okazaki, Kasugai, Toyota, Tsu, Otsu, Kishiwada, Kakogawa, Kurashiki, Omuta	1.80	1473.0
	$F_2 \leqq -1$	IX	18	Obihiro, Hirosaki, Aizuwakamatsu, Kumagaya, Matsumoto, Ise, Suzuka, Tottori, Matsue, Ube, Iwakuni, Imabari, Niihama, Saga, Yatsushiro, Beppu, Miyakonojo, Nobeoka	3.47	1572.1

second components at every city, and devides them into three groups by their scores, and then classifies them into nine groups according to their combination. Its result[26] is shown in Table 4. We can roughly put an interpretation on these city groups as follows;

Type I shows the satellite cities which are included in such metropolitan areas as Tokyo and Osaka city, and shows great cities that have a little independence. Type II, III and VI are the cities which occupy a central place at local regions, and a large number of the administrative central city of each prefecture are comprehended in these groups. Type V, VIII are placed under the II, III and VI groups, that is, they are medium and small cities at local regions. Type IV is situated in the outside places of the metropolitan areas of Tokyo, Osaka or Nagoya city, and type VII indicates the cities that are situated in the inside of these largest metropolitan areas, and that have rapidly expanded in recent years. Type IX is the cities of a falling tendency from the view point of their population growth.

The mean values of a-value and the coefficient of inflow in each group are in proportion to F1-value and in inverse proportion to F2-value. That is, as the functions of the city is getting greater, so its centrality against outlying area is growing. Furthermore, as the traffic facilities to central cities improved, the degree of the tendency of satellite cities increases in the case of cities situating in the suburbs of a metropolis, so they are apt to depend upon the central city more and more.

For the quantitative analysis of the next paragraph, the author classified the cities into four groups by the average of the coefficient of inflow and the index number of mobility in accordance with the outflowing and inflowing population of each city.

$$IM_i=(T_i-M)/\sigma_T \quad \cdots\cdots(10)$$

where

IM_i : the index number of mobility of i-th city.

T_i : the mobility of i-th city as defined in Table 5.

σ_T : the standard deviation of T_i.

M : the arithmetic mean value of T_i.

It is named a classification of cities owing to the mobility and is shown in Fig. 3.

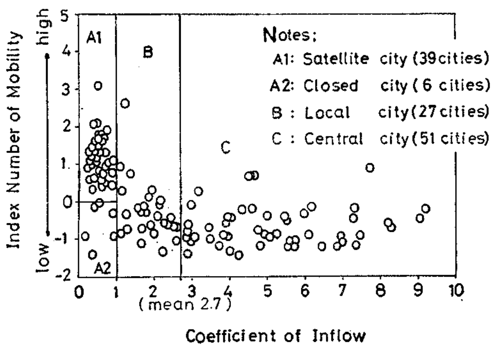

Fig. 3 A Classification of Cities owing to the Mobility.

(2) The Quantitative Analysis of the Structures of City-Region

The author applies a simple correlation analysis and multiple linear regression analysis to this problem, with the aid of the population of city-region (shown in Table 1) as the scale of city-region, and with the aid of the city functions (shown in Table 5) as the scale of a central city. The population of city-region is represented with the amount of resident population within the sphere of the primary limit (excluding the population of the central city). This value is equal to zero, when other cities, towns or villages do not exist within the primary limit. And if they have a large population over that of the central city in question, their population does not count at all.

Table 5 Correlation Coefficient between the Functions of the Central City and the Population of City-Region

Functions of a central city			Correlation coefficient(3)				
No.	Name	Unit	All cities	A1	A2	B	C
X_1	Population	10 persons	0.498	0.197	0.708	0.521	0.652
X_2	DID population	10 persons	0.417	0.170	0.265	0.422	0.623
X_3	the rate of the Primary industrial workers to the population	%	−0.014	0.263	−0.152	−0.217	−0.315
X_4	the rate of the Secondary industrial workers to the population	%	−0.130	−0.097	0.641	0.135	0.024
X_5	the rate of the Tetiary industrial workers to the population	%	0.168	−0.057	−0.418	0.008	0.266
X_6	the population density	person/km²	−0.017	0.491	0.837	0.140	0.636
X_7	the rate of population growth	%	−0.213	−0.218	0.127	0.140	0.310
X_8	the number of local agencies of the national government	office	0.592	0.283	−0.133	0.430	0.617
X_9	the number of financial agencies	office	0.679	0.302	0.620	0.542	0.710
X_{10}	the number of employed persons	person	0.630	0.178	0.836	0.593	0.748
X_{11}	the number of managing workers	person	0.503	0.143	0.600	0.642	0.666
X_{12}	the number of business establishments	office	0.680	0.254	0.859	0.600	0.765
X_{13}	the number of public officials	person	0.350	0.040	−0.024	0.281	0.401
X_{14}	the amount of wholesale selling	10 million Yen	0.671	0.329	0.682	0.584	0.710
X_{15}	the amount of retailsale selling	10 million Yen	0.573	0.127	0.437	0.603	0.649
X_{16}	the number of houses under construction	houses	0.423	0.165	0.303	0.269	0.709
X_{17}	the amount of selling of eating places	million Yen	0.636	0.161	0.432	0.637	0.713
X_{18}	the number of service workers	person	0.551	0.177	−0.173	0.541	0.661
X_{19}	the amount of deposit of financial agencies	10 million Yen	0.705	0.310	0.897	0.548	0.796
X_{20}	the number of colleges, universities & senior-high schools	school	0.610	0.192	0.171	0.544	0.685
X_{21}	the number of junior-high schools & elementary schools	school	0.499	0.201	0.516	0.407	0.525
X_{22}	the number of teachers	person	0.592	0.276	0.490	0.460	0.653
X_{23}	the rate of water supply	%	0.003	−0.129	−0.361	0.139	0.243
X_{24}	the rate of telephone subscriber	telephone/100 persons	0.255	−0.120	0.646	0.550	0.590
X_{25}	the coefficient of inflow(1)		0.133	0.234	0.143	0.225	−0.038
X_{26}	mobility(2)		−0.178	−0.294	0.311	0.089	0.447
X_{27}	the inflowing population	person	0.513	0.062	0.946	0.715	0.925
X_{28}	the outflowing population	person	−0.164	0.084	0.451	0.392	0.792

Notes: (1) $X_{25}=X_{27}/X_{28}$
(2) $X_{26}=(X_{27}+X_{28})/X_1$
(3) A1, A2, B and C are shown in Fig. 3.

Table 6 Analysis of Variance for Multiple Linear Regression

Souce of variation	Degrees of freedom	Sum of squares	Mean of squares	F-value	Significance level (P)
Regression	4	2545794	636449	60.07	$P<0.001$
Residual	118	1250162	10595		
Total	122	3795956			

The correlation coefficients between the functions of the central city and the population of city-region are shown in Table 5[27].

Generally speaking, as the city functions become greater, the structure of city-region is much influenced by both factors signifying the centrality of work and schooling, such as the number of offices and schools, and signifying the centrality of services, such as amount of selling of retail stores, wholesale stores or eating places. On the contary if the city has less function, the latter factor is predominant. In the satellite cities within the metropolitan areas, we can not find out distinct relations about them.

In the next step, as the quantitative model of the structures of city-region, the author takes advantage of the multiple linear regression analysis which can be expressed by the following equation;

$$Y=l_1X_1+l_2X_2+\cdots+l_nX_n+m \quad \cdots\cdots\cdots\cdots(11)$$

where

Y: the scale of city-region.

$X_1, \cdots, X_n$: the functions of a central city.

$l_1, \cdots, l_n, m$: the coefficients.

It is desired that the mathematical model is made to be as simple as possible. Then by investigating the degree of contribution of each variable at equation (11), the author tries to make the model include variables which shows higher contribution, and exclude valiables which shows low degree of it.

Two methods are applied for this purpose, one is the step-wise method, and the other is the varimax method, a kind of factor analysis. We get a good result at the former method and can describe it as follows;

$$\begin{aligned} Y = & -0.0134X_2+0.0182X_{12}+0.0196X_{19} \\ & (-7.7343) \quad (4.2501) \quad (4.1484) \\ & +0.0036X_{27}+9.42 \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots(12) \\ & (4.2173) \quad (r\text{: } 0.8189) \end{aligned}$$

where

Y : the population of city-region (1 000 persons).

X_2 : the DID population (10 persons).

X_{12}: the number of buisiness establishments (office).

X_{19}: the amount of deposit of financial agencies (10 million Yen).

X_{27}: the inflowing population (person).

The figure in parentheses is t-value and r represents the multiple correlation coefficient.

The author has used the analysis of variance for testing goodness of fit of multiple linear ression. Its result is shown in Table 6.

The indices which denote a concentration of the city function are selected at equation (12).

Although there is a positive correlation between Y and X_2 (see Table 5), the partial regression coefficient at equation (12) is a negative number. This phenomenon may be caused by the influence of the multicollinearity. So considering a model for further discussion, there is much room for further improvement. For instance, the building of a model based on classification of cities and so on.

6. CONCLUSION

The author has intended to advance a general theory of city-region's structures with a complex mechanism. In order to accomplish this purpose, some models are proposed and the areas selected for study include 123 cities. The results of these analyses are summarized as follows;

① Traffic distribution model

The P/M curve is an effectual model, and a coefficient a denotes an index which illustrates the centrality of city.

② The hypothesis of city-region

It should be good enough to take the primary limit as the boundary of the hypothesis of city-region. Its values are different from each city, but are mostly within the range of 60 minutes.

③ The analyses of the structures of city-region

We can presume the structures of city-region, according to the scale of a central city, the convenience of traffic facilities and in addition to these, the classification of cities. There is a positive correlation between both the scales of a central city and its city-region.

As the a-value or the coefficient of inflow becomes larger, the scale of the city-region becomes greater. However no definite relation can be found in the satellite cities.

④ The traffic accessibility

Since the directions of traffic flow are influenced by the facilities of transportation, the spheres of the city-region expand elliptically along the railway line, but the spheres of the cities located near the neighbouring prefectures do not extend to other prefectures, except for metropolitan areas surrounding Tokyo and Osaka city. This might be originated in the fact that consciousness distance exerts much influence.

As a subject for further discussion, the author intends to study the changes of the structures of city-region by means of the time series materials and its analysis from the view point of demographic energy[28].

ACKNOWLEDGEMENTS

The author extends his heartfelt thanks to Professor Ogawa, H. and Assistant Professor Igarashi, H. of Hokkaido University for giving him the kind advice and important suggestions throughout this research.

Finally, the calculations for the analyses were done by NEAC model 2200 of Tohoku University Computing Center.

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(*Received May 24, 1974*)