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Yukio Sadahiro and Mitsuru Umemura

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Center for Spatial Information Science and Department of Urban Engineering
University of Tokyo
7-3-1, Bunkyo-ku, Tokyo 113-8656, Japan

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*Center for Spatial Information Science and Department of Urban Engineering
**Department of Urban Engineering
University of Tokyo
7-3-1, Hongo, Bunkyo-ku, Tokyo 113-8656, Japan

Phone: +81-3-5841-6273
Fax: +81-3-5841-8521
E-mail: sada@okabe.t.u-tokyo.ac.jp

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Abstract

This paper develops a method for analyzing changes in polygon distributions. Four types of topological events are proposed to describe the change: 1) generation, 2) disappearance, 3) union, and 4) division. Any change of polygon distributions can be decomposed into a combination of these events. From polygon distributions of two times a set of events causing the change is estimated. Me asures summarizing the change of polygon distributions are then proposed. They are essentially based on the number of events, thus represent the complexity of change. The method is applied to the analysis of the spatial competition between the major and small chains of convenience stores in Tokyo, Japan. The empirical study reveals the spatial structure of competition in both local and global scales.

1. Introduction

Polygons, as well as points and lines, are most important spatial objects in GIS. Geological maps describe the spatial configuration of soils by polygons. Landuse maps contain polygons representing commercial areas, residential areas, parking lots, urban parks, and so forth. Polygons are also created from points and lines by spatial operations. Thiessen polygons are constructed from a set of points. Buffer operation generates polygons approximating curved figures from points and lines.

Polygons often change their shape and location over time. Consider, for instance, spatio-temporal changes in a city in which geographers have a great interest. A residential area expands with urban growth. A business district appears at the city center. Emergence of supermarkets causes declination of shopping streets; old stores are closed and retail clusters shrink. These changes are represented as the spatio-temporal change of polygons in GIS.

Geography, especially spatial analysis, is concerned with such changes, and GIS provides several functions to analyze them. One is overlay operation, which superimposes polygon distributions of different times on a base map to investigate changes between them. Another option is to see the change by animation. Since recent GIS can generate animation from sectional data, this method is now widely available.

The above methods are too naive as methodology of spatial analysis, though they are essential in exploratory data analysis. A more sophisticated method is to calculate summary statistics for individual times and analyze their temporal change. The average and total area of polygons are widely used. Such measures, however, fail to take spatial changes into account because they are based on the sectional data. Therefore, they cannot detect even basic transformations of polygons such as translation and rotation, though they are significant changes in the real world.

In GIS field, spatio-temporal changes have been studied chiefly by computer scientists. Galton (1997), for instance, analyzes various types of continuous change in polygons. Using several measures of separation between polygons, he examines how change processes are represented. Egenhofer and Al-Taha (1992) discuss the gradual change of a polygon from the viewpoint of spatial relations. They propose a graph representing the closest topological relationship between spatial relations, and describe the change of spatial relation between two polygons caused by the change of one of the polygons. Hornsby and Egenhofer (1997, 1998) introduce a framework for representing the spatio-temporal change of spatial objects in GIS. Using a qualitative representation of change, they classify various types of change and operation. The above studies provide computational models to represent spatio-temporal changes. However, since they focus on spatial information theory rather than spatial analysis, they are not applicable directly to the spatio-temporal analysis of polygon distributions.

This paper develops a method for analyzing the spatio-temporal change of the distribution of polygons. We focus on polygons that do not move in space, say, residential lots and parks. In section 2, we propose four types of topological events to describe the change of polygon distributions. From polygon distributions of two times we estimate a set of events that cause the change. We also propose several measures to summarize the change of polygon distributions. In order to test the validity of the method, section 3 empirically analyzes the spatial competition between the major and small chains of convenience stores in Tokyo, Japan. Section 4 summarizes the conclusions with discussion.

2. Methodology

Spatio-temporal distribution of polygons can be represented in several ways in current GIS (Langran, 1992). One is the layer-based approach in which each layer indicates a snapshot of polygon distributions at a certain time. Another method describes temporal information as attributes of polygons, say, the time of birth and death (object-oriented approach). This paper assumes the former representation, that is, we analyze the spatio-temporal change of polygon distributions using sectional data. Note, however, that the method we propose can be applied to object-oriented data with a slight modification.

Suppose n sets of polygons Γ_1, Γ_2, ..., Γ_n, where Γ_i represents the distribution of polygons at a time t_i. Let $\#(\Gamma)$ and $A(\Gamma)$ be the number and total area of polygons in a polygon set Γ, respectively. We first propose a method for analyzing the change between two times, from t_1 to t_2, and then extend it to the case of $n(>2)$ times.

We adopt the definition of a polygon as an open set of points; the boundary does not belong to the polygon. It allows us to treat adjacent polygons as separated (Figure 1). In order to distinguish boundaries shared by two polygons from outer boundaries, we call the former *partition* and the latter *boundary* hereafter.

Figure 1 An example of polygon sets Γ_1 (left) and Γ_2 (right).

2.1 *Classical summary statistics*

Given two sets of polygons Γ_1 and Γ_2, we can calculate several summary statistics as below.

1) Number ratio: the ratio of the number of polygons in Γ_2 and Γ_1.

$$r_{NUMBER} = \frac{\#(\Gamma_2)}{\#(\Gamma_1)} \tag{1}$$

2) Total area ratio: the ratio of the area of polygons in Γ_2 and Γ_1.

$$r_{AREA\_TOTAL} = \frac{A(\Gamma_2)}{A(\Gamma_1)} \tag{2}$$

3) Average area ratio: the ratio of the average area of polygons in Γ_2 and Γ_1.

$$\begin{aligned} r_{AREA\_AVERAGE} &= \frac{A(\Gamma_2)/\#(\Gamma_2)}{A(\Gamma_1)/\#(\Gamma_1)} \\ &= \frac{r_{AREA\_TOTAL}}{r_{NUMBER}} \end{aligned} \tag{3}$$

These statistics partly describe how a polygon distribution changes; whether the number, total area, and average area of polygons increase. However, since they are calculated only from sectional data, they provide little information about spatial changes. They cannot detect the change from Γ_1 to Γ_2, for instance, if Γ_2 is obtained by a translation of Γ_1. More detailed description of spatio-temporal changes is necessary in spatial analysis.

2.2 *Event-based method*

In order to take spatial changes into account more explicitly, we consider four types of topological events that occur in polygon distributions: 1) *generation*, 2) *disappearance*, 3) *union*, and 4) *division* (Figure 2). Any change of polygon distributions can be described by a combination of these events as shown later.

Figure 2 Topological events. (a) Generation, (b) disappearance, (c) union, and (d) division.

The set Γ_1 changes into Γ_2 by a sequence of topological events. It is not known, however, what events occurred between t_1 and t_2. We thus estimate the topological events that occurred from t_1 to t_2. Note that we do not estimate the change process itself; we are interested in the combination of events rather than their order.

There are numerous possible combinations of topological events causing the change from Γ_1 and Γ_2. To choose the most plausible one we follow two principles. The principle of *minimum events* is that a set of fewer events is more plausible, that is, we choose the smallest number of events. Similar ideas are often used in spatial reasoning (for example, see Egenhofer and Al-Taha, 1992). The second principle is *change without redundancy*, which assumes that no two changes occur at the same location between two times. For instance, the change shown in Figure 3a is inhibited while that in Figure 3b is acceptable. The points on the boundary of two right polygons are generated at the first step and then disappeared in Figure 3a.

Figure 3 Two changes causing the same result. (a) The inhibited change, (b) the permissible change.

Following the above two principles we can estimate the topological events that occurred from t_1 to t_2. Figure 4 shows some examples of the change and the estimated combination of events. Concerning the order of events, there may be more alternatives other than those shown in Figure 4.

Figure 4 Changes of polygon distributions and the estimated combinations of events.

Computational procedure of estimation is as follows. The polygon sets Γ_1 and Γ_2 are overlaid to generate a new set of polygons. Each polygon is labelled two variables (S_1, S_2), where S_i indicates the state of the polygon at t_i. The variables take either E or $\varnothing$: E stand for *Existing* and $\varnothing$ for *Not-existing*. For instance, a polygon whose elements (points) exist in both Γ_1 and Γ_2 is labelled (E, E). The label ($\varnothing$, E) implies the generation of a polygon, while (E, $\varnothing$) is a disappearance event. Figure 5b shows an example of labels.

The polygons generated by overlay operation are classified by label into three subsets Ω_0, Ω_1, and Ω_2. The set Ω_0 is a set of polygons labelled (E, E). The sets Ω_1 and Ω_2 consist of polygons labelled ($\varnothing$, E) and (E, $\varnothing$), respectively.

The arcs generated by overlay operation are also labelled two variables (S_1, S_2). The variables take one of the four values: B, P, I, or $\varnothing$. Arcs that compose the boundary and partition of polygons are labelled B and P, respectively. Arcs belonging to the interior of polygons have I, which appear when a boundary changes into a part of a polygon by a union event. The empty set $\varnothing$ represents the absence of arcs. The variables (S_1, S_2) enable us to classify arcs into twelve groups: (B, B), (B, P), (B, I), (B, $\varnothing$), (P, B), (P, P), (P, I), (P, $\varnothing$), (I, B), (I, P), ($\varnothing$, B), and ($\varnothing$ P). Figure 5c depicts the label of arcs representing their state at t_1 and t_2.

Figure 5 Labels representing the state of polygons and arcs at t_1 and t_2. (a) A change of polygons, (b) labels for polygons, (c) labels for arcs.

Using the label of polygons and arcs we can estimate the smallest number of topological events that yield the change from Γ_1 to Γ_2. Concerning generation and disappearance events, estimation is straightforward. The smallest number of these events can be easily obtained by counting the number of polygons labelled (E, $\varnothing$) or ($\varnothing$, E). The polygons labelled ($\varnothing$, E) give the smallest set of generation events, while the number of (E, $\varnothing$) polygons is the smallest number of disappearance events. Let G and Dis be the sets of estimated generation and disappearance events, respectively. Each event is denoted by its own number: the *i*th generation event, for instance, is denoted by G_i. Let $P(G_i)$ be the polygon generated by G_i. Similarly, $P(Dis_i)$ is the polygon disappeared at the *i*th disappearance event.

Estimation of union events is somewhat complicated. We examine all the arcs to find labels (B, I) and (P, I) where unions must have occurred (Figure 6a). We then extract the nodes shared by only (B, I) or (P, I) arcs, which define connecting groups of arcs as shown in Figure 6b. For each group of arcs we calculate the number of polygons that are at least partly bounded by the arcs. Subtracting one from the number we obtain the smallest number of union events that occurred at the arc group. Division events can be estimated in a similar way.

Union and division events are estimated at an aggregated level so that it is impossible to identify individual events; for instance, there are three ways of combining polygons shown in Figure 6b. We thus denote U_i as the *i*th set of union events that cannot be decomposed further into individual events. Let $PO(U_i)$ and NU_i be the set and number of polygons combined by U_i, respectively. The resultant polygon is denoted by $PR(U_i)$. Similarly, Div_i indicates the *i*th set of division events and ND_i is the number of resultant polygons. The original polygon and the set of resultant polygons involved with Div_i are denoted by $PO(D_i)$ and $PR(Div_i)$, respectively.

Figure 6 Estimation of union events in the change of polygons shown in Figure 5. (a) Arcs where unions must have occurred (thick broken lines) and a node shared by only (B, I) or (P, I) arcs (the white circle), (b) a connecting group of arcs (thick solid lines) and the polygons bounded by the arcs (gray-shaded regions).

The estimated topological events and the polygons involved with the events fully describe the change from Γ_1 to Γ_2. However, the information they provide is too abundant for direct use in spatial analysis. We thus propose several measures to summarize the change from Γ_1 to Γ_2.

One simple but useful measure is the total number of events given by

$$M_{EVENT} = \#(G) + \#(Dis) + \sum_{i=1}^{\#(U)} NU_i + \sum_{i=1}^{\#(Div)} ND_i \, , \tag{4}$$

where #(S) indicates the number of elements in a finite set S. This measure shows a large value if many events occur from t_1 to t_2.

However, this measure is somewhat inconvenient if we compare the spatio-temporal change between different sets of polygons; the number of events necessarily increases with that of original and resultant polygons. We thus standardize M_{EVENT} by dividing it by the number of polygons in Γ_1 and Γ_2:

$$m_{EVENT} = \frac{\#(G)+\#(Dis)+\sum_{i=1}^{\#(U)} NU_i + \sum_{i=1}^{\#(Div)} ND_i}{\#(\Gamma_1)+\#(\Gamma_2)}. \tag{5}$$

We call this measure the *event measure*. The event measure represents the degree of change in terms of events, in other words, the complexity of change. For instance, a large m_{EVENT} implies that many events occurred from t_1 to t_2, that is, the change was quite complicated. The measure m_{EVENT} shows zero if and only if the polygons in Γ_1 and Γ_2 are exactly the same.

A more general form of the measure is

$$\begin{aligned} m_{GENERAL} = \frac{1}{g(\Gamma_1)+g(\Gamma_2)} \Bigg[& \sum_{i=1}^{\#(G)} f_G\big(P(G_i)\big) + \sum_{i=1}^{\#(Dis)} f_{Dis}\big(P(Dis_i)\big) \\ & + \sum_{i=1}^{\#(U)} f_U\big(PO(U_i), PR(U_i)\big) + \sum_{i=1}^{\#(Div)} f_{Div}\big(PO(Div_i), PR(Div_i)\big) \Bigg]. \end{aligned} \tag{6}$$

Substituting

$$f_G\big(P(G_i)\big) = f_{Dis}\big(P(Dis_i)\big) = 1, \tag{7}$$

$$f_U\big(PO(U_i), PR(U_i)\big) = NU_i, \tag{8}$$

$$f_{Div}\big(PO(Div_i), PR(Div_i)\big) = ND_i, \tag{9}$$

and

$$g(\Gamma) = \#(\Gamma) \tag{10}$$

we obtain equation (5).

Equation (5) implies that the four kinds of events are equivalent in the sense of complexity. If this assumption is not acceptable, we can weight each type of event with its complexity:

$$f_G\big(P(G_i)\big) = \alpha_G, \tag{11}$$

$$f_{Dis}\big(P(Dis_i)\big) = \alpha_{Dis}, \tag{12}$$

$$f_U\big(PO(U_i), PR(U_i)\big) = \alpha_U NU_i, \tag{13}$$

and

$$f_{Div}\big(PO(Div_i), PR(Div_i)\big) = \alpha_{Div} ND_i. \tag{14}$$

Substituting these equations (10)-(14) into equation (6) we have the *weighted event measure*

$$m_{WEIGHTED} = \frac{\alpha_G \#(G) + \alpha_{Dis} \#(Dis) + \alpha_U \sum_{i=1}^{\#(U)} NU_i + \alpha_{Div} \sum_{i=1}^{\#(Div)} ND_i}{\#(\Gamma_1) + \#(\Gamma_2)}. \tag{15}$$

The event and weighted event measures are both based only on the topology of events; they do not incorporate metric information about events. However, we can take metric factors into account by adopting metric functions in equation (6). For instance, if we consider that the generation of a large polygon is a greater change than that of a small polygon, we may use

$$f_G(P(G_i)) = A(P(G_i)) \tag{16}$$

and

$$f_{Dis}(P(Dis_i)) = A(P(Dis_i)). \tag{17}$$

In addition to these equations, we substitute

$$f_U(PO(U_i), PR(U_i)) = f_{Div}(PO(Div_i), PR(Div_i)) = 0 \tag{18}$$

and

$$g(\Gamma) = A(\Gamma) \tag{19}$$

into equation (6) to obtain

$$m_{AREA} = \frac{A(\Omega_1) + A(\Omega_2)}{A(\Gamma_1) + A(\Gamma_2)}. \tag{20}$$

We call this measure the *area measure*.

2.3 *The case of n(>2) times*

Classical summary statistics and event-based measures describe the change of polygon distributions between two times. This subsection extends the methods to the case of n(>2) times --- the change from Γ_1 to Γ_n.

Extension of the classical statistics, that is, the number ratio, total area ratio, and average area ratio, is straightforward; we calculate these statistics for the first and last times, say,

$$r_{NUMBER} = \frac{\#(\Gamma_n)}{\#(\Gamma_1)}. \tag{21}$$

The event-based measures are calculated as follows. We first estimate the topological events that occurred between every neighboring times using the method proposed in the previous subsection. Enumerating the events we obtain a set of plausible events from t_1 to t_n, and classify them into the four groups: G, Dis, U, and Div. The measures are calculated on the basis of these events and the sets of polygons at t_1 and t_n, say,

$$m_{GENERAL} = \frac{1}{g(\Gamma_1) + g(\Gamma_n)} \left[\sum_{i=1}^{\#(G)} f_G\left(P(G_i)\right) + \sum_{i=1}^{\#(Dis)} f_{Dis}\left(P(Dis_i)\right) \right. \\ \left. + \sum_{i=1}^{\#(U)} f_U\left(PO(U_i), PR(U_i)\right) + \sum_{i=1}^{\#(Div)} f_{Div}\left(PO(Div_i), PR(Div_i)\right) \right]. \tag{22}$$

3. Empirical study

In the previous section we proposed a method for analyzing the spatio-temporal change of polygon distributions. To test the validity of the method, this section empirically analyzes the spatial competition among convenience stores in the Tokyo 23-ku area in Japan.

Most convenience stores belong to retail chains in Japan; one third of stores belong to one of three major chains (7-Eleven, Family Mart, and Lawson). There is keen competition among chains, especially between the major chains and other small chains. We are concerned with the spatial competition between the major and small chains.

Spatial data used in the analysis are based on the list of convenience stores in the *NTT telephone directory* which is published every month. We obtained the address of convenience stores in September every year from 1990 to 98 in ASCII format, and converted it into geocoded data by address matching. Figure 7 shows the number of stores in the Tokyo 23-ku area from 1990 to 98.

Figure 7 The number of convenience stores in the Tokyo 23-ku area, 1990-98.

Figure 7 indicates that the stores of the major chains increased rapidly from 1990 to 94 while those of the small chains increased moderately. Since 1994, however, both the major and small chains grew at a similar speed. We thus analyzed the spatial competition between the chains separately for two periods: 1990 to 94 and 94 to 98.

Analysis is based on the market area of chains which is estimated from the point data of convenience stores. As for the consumer behavior, we assume that they go to the nearest stores, and that they do not use convenience stores located further than 400 meters. These assumptions are reasonable in urban areas in Japan. Market area is then given by the Voronoi diagram of convenience stores clipped by a buffer region of distance 400 meters. Table 1 shows the number of stores and the size of market area.

Table 1 The number of stores and the size of market area, 1990-98.

The total market area of all chains was stable during 1990-98. This is because in

1990 convenience stores were already enough to cover the Tokyo 23-ku area with market area. In spite of that, the number of stores increased in both the major and small chains, which reduced the average market area of stores.

Since the total market area was almost unchanged, it is sufficient to examine the change of market area of the major chains in order to analyze the spatial competition between the major and small chains. Table 2 shows the number and area of polygons representing the market area of the major chains in 1990, 94, and 98. The ratios discussed in Subsection 2.1 (the number, total area and average area ratios) were also calculated.

Table 2 The number and area of polygons representing the market area of the major chains.

The total area of polygons increased noticeably from 1990 to 94. This indicates that the major chains invaded the market area of the small chains. In contrast, the total area is rather stable after 1994. It seems, at least from these figures, that the major and small chains were in equilibrium in this period. We also calculated the ratios at the ward level, but the results were quite similar.

We then move to the complexity of change of market area. Topological events discussed in the previous section imply the spatial competition between the chains. We thus calculated two event-based measures for each ward (Figure 8): the area measure m_{AREA} and the event measure m_{EVENT}. A large value of these measures indicates that the market area changed considerably, that is, the major and small chains competed actively with each other.

Figure 8 Twenty-three wards in the Tokyo 23-ku area.

The results are shown in Table 3. We notice that the total area ratio and the area measure are positively correlated (r=0.68). This implies that a large value of the area measure is yielded by the expansion of market area of the major chains. For instance, the area measure is larger in 90-94 than 94-98 in most wards. This is chiefly because the market area of the major chains expanded drastically from 1990 to 94. The event measure, on the other hand, is larger in 94-98 than 90-94; more events occurred during the latter period. From this we can say that the major and small chains competed keenly in both periods: from 1990 to 94 the major chains clearly gained in strength; after 1994 the competition was still keen but almost even.

Table 3 Event-based measures.

We then investigate the spatial structure of competition between the chains in a global scale using the area and event measures. Figure 9 confirms that the area measure decreased considerably from 90-94 to 94-98. Its spatial distribution slightly changed; the area measure decreased more drastically in the north than in the south. Concerning the event measure, its value increased equally in all the wards, keeping its global structure (Figure 10). Considering these results, we can say that the spatial structure of competition was rather stable in a global scale during 1990-98; the situation became more competitive from 90-94 to 94-98 in all the wards; the expansion of the major chains became somewhat slower in the north.

Figure 9 The area measure.

Figure 10 The event measure.

We finally examine the spatial competition in a local scale. Figure 11 shows the change of market area of the major chains from 1990 to 1994 in Chuo, Taito, and Shinagawa. Chuo is distinctive for its large area measure and small event measure, which is confirmed by Figure 11a. There were only a few convenience stores in 1990 so that a lot of space was left as potential market area. The competition was not so keen, thus the area measure is large while the event measure is small. Taito and Shinagawa are similar in the area measure but different in the event measure. Shinagawa has a large event measure, which is confirmed by the drastic change of market area shown in Figure 11c.

Figure 12 shows the change of market area from 1994 to 1998 in Bunkyo, Shibuya, and Itabashi. The total area ratio of these wards is almost the same as the average for all the wards. Variation in the area measure is so small that it can be ignored. The difference among these wards lies in the event measure: Itabashi shows the largest value among all the wards, while Bunkyo has quite a small value. The competition between the major and small chains was much stronger in Itabashi than Bunkyo, as depicted in Figure 12.

Figure 11 The change of the market area of the major chains from 1990 to 94 in (a) Chuo, (b) Taito, and (c) Shinagawa.

Figure 12 The change of the market area of the major chains from 1994 to 98 in (a) Bunkyo, (b) Shibuya, and (c) Itabashi.

4. Concluding discussion

In this paper we have developed a method for analyzing the spatio-temporal change of polygon distributions. Four types of topological events are introduced to describe the change: 1) generation, 2) disappearance, 3) union, and 4) division. Any change of polygon distributions can be decomposed into a combination of these events. From polygon distributions of two times a set of events causing the change is estimated. To summarize the change of polygon distributions we proposed several measures, say, the event measure. They reflect the number of events that occurred between two times, and thus represent the complexity of change. The general form of the measures, $m_{GENERAL}$, can take account of not only the topological information but also the metric information such as the area of polygons. We then applied the method to the analysis of spatial competition between the major and small chains of convenience stores in Tokyo, Japan. The empirical study revealed the spatial structure of competition in both local and global scales.

The event-based approach is useful for spatio-temporal analysis of polygon distributions. However, this does not assure that the method is applicable to any types of polygons. We finally discuss the limitations of the method for further research.

First, we proposed the four types of events as mentioned above, assuming that polygons are not movable. This implies that the method does not work well if polygons can move; we additionally have to consider *movement* events (Galton, 1995). Taking movement into account causes difficulties in estimating the change process, and thus the extension of the method is not straightforward. However, the difficulties have to be overcome in future research to treat movable polygons appropriately in spatial analysis.

Second, the event-based method assumes that polygons are homogeneous; attribute information of polygons is not used. This does not matter at an early stage of spatial analysis. At an advanced stage, however, it may be necessary to analyze the temporal change in both spatial and aspatial aspects. An extension in this direction is also important.

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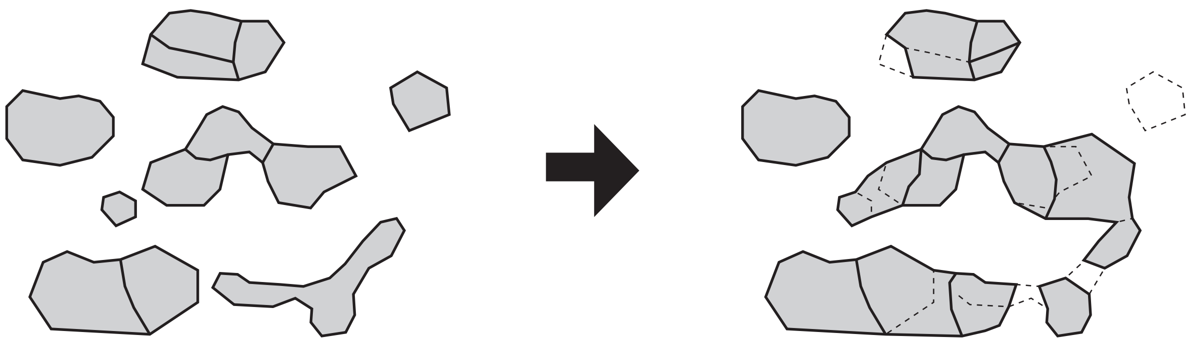


Figure 1

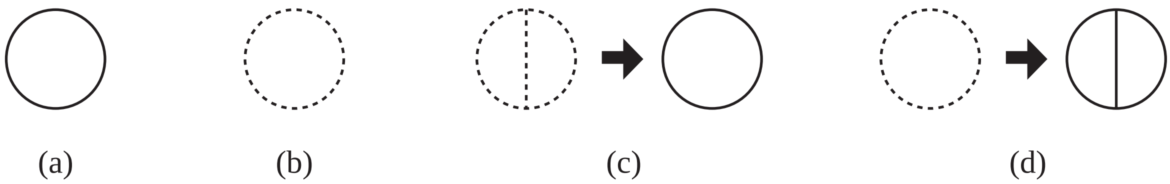
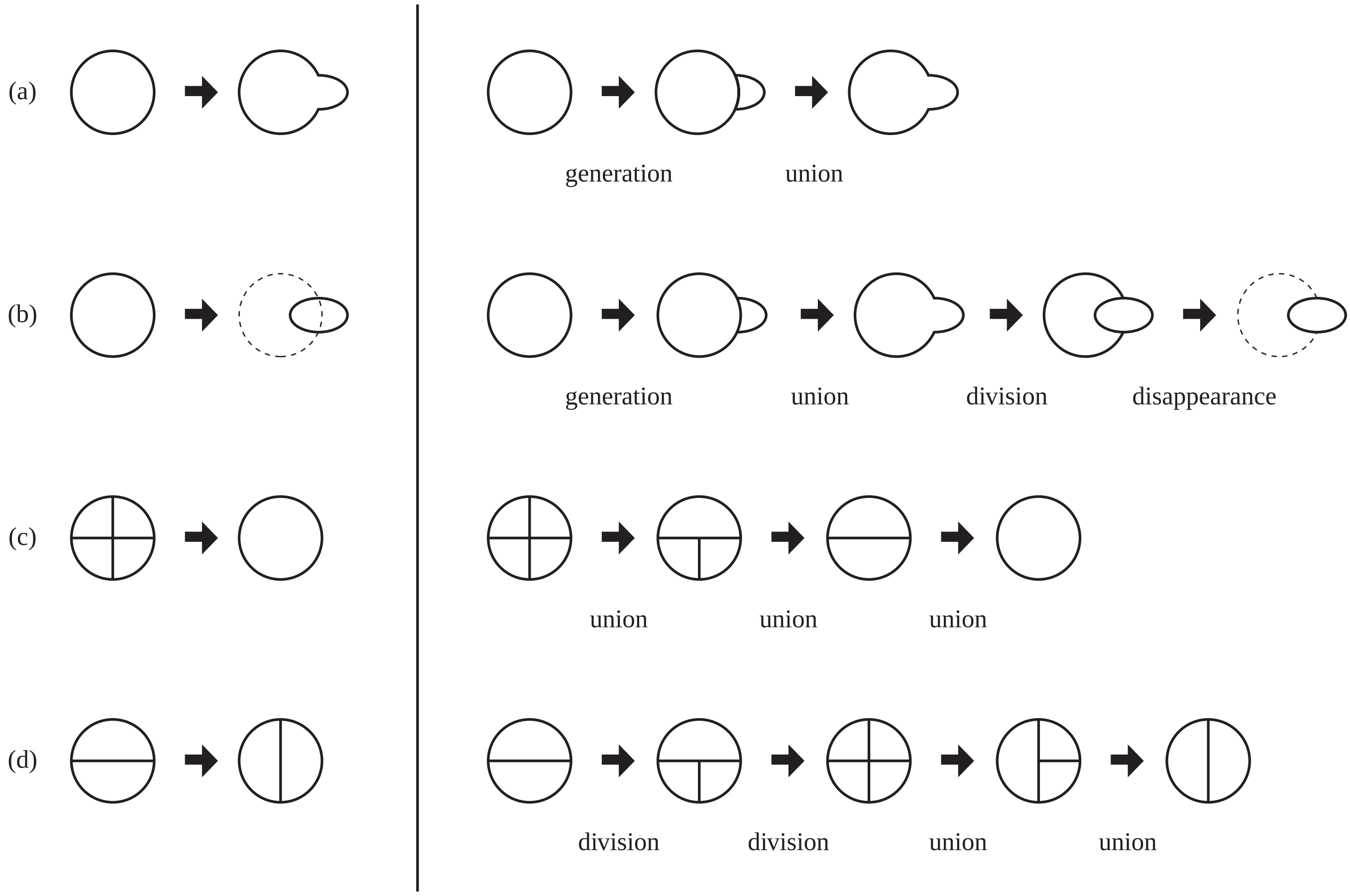


Figure 2

(a) (b)

Figure 3


(a)
generation
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disappearance
(c)
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union
union
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division
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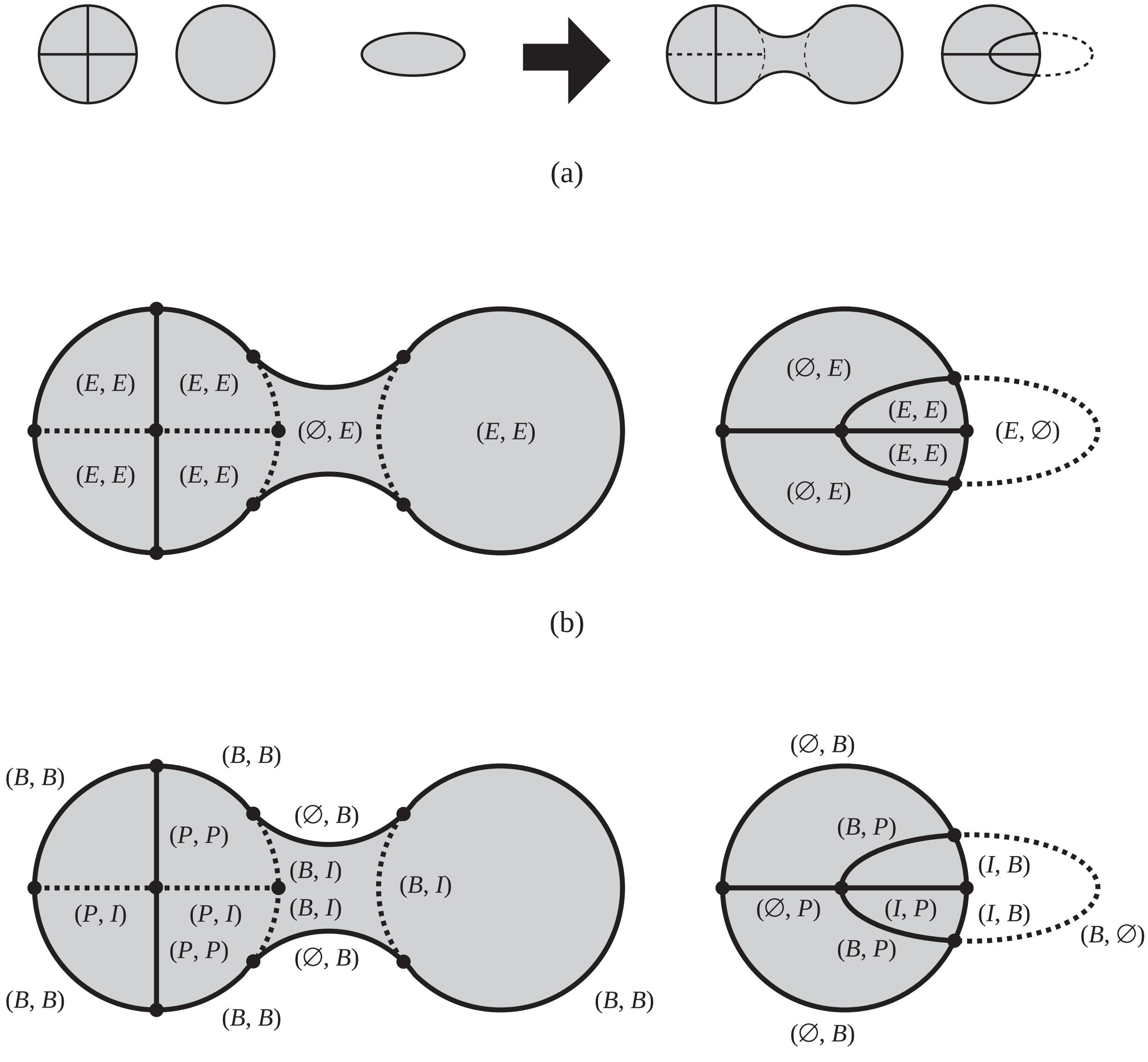
union

Figure 4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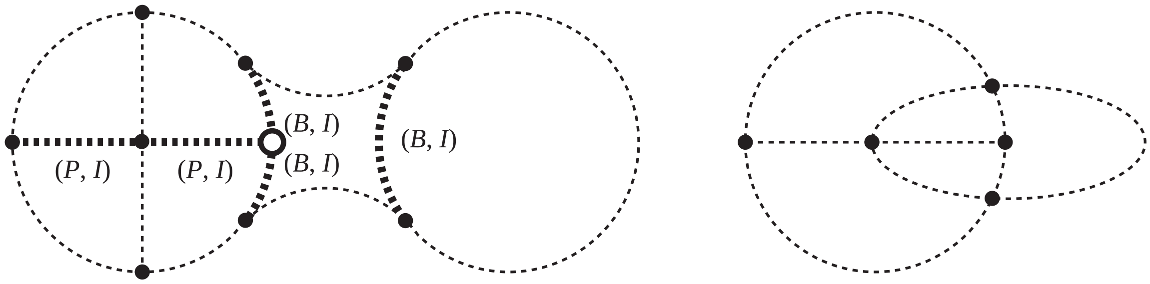
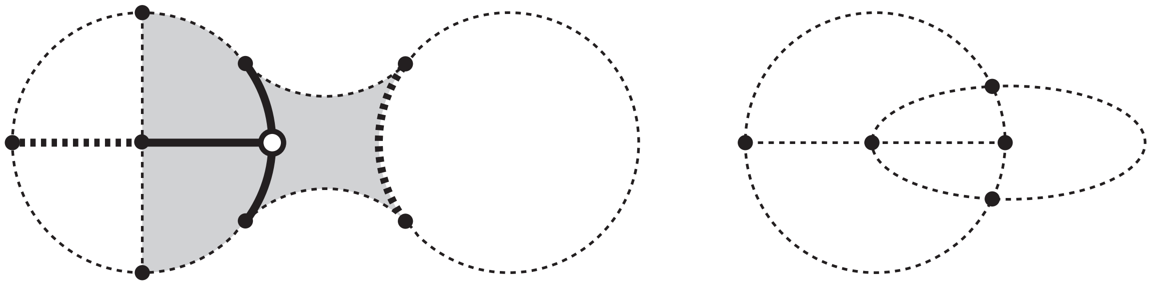
(∅, B)
(c)

Figure 5



(a)



(b)

Figure 6

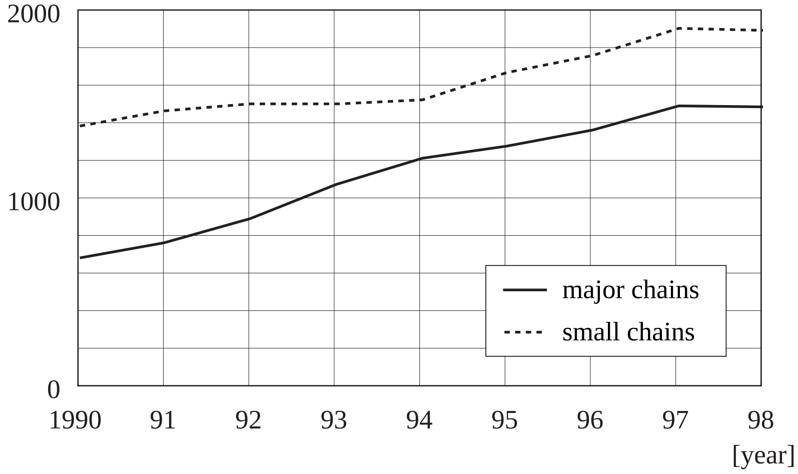

2000
1000
0
1990
91
92
93
94
95
96
97
98
[year]
major chains
small chains

Figure 7


Adachi
Itabashi
Kita
Nerima
Katsushika
Arakawa
Toshima
Nakano
Bunkyo
Taito
Sumida
Shinjuku
Suginami
Edogawa
Chiyoda
Shibuya
Chuo
Koto
Minato
Setagaya
Meguro
Shinagawa
Ota
N
0
5km

Figure 8

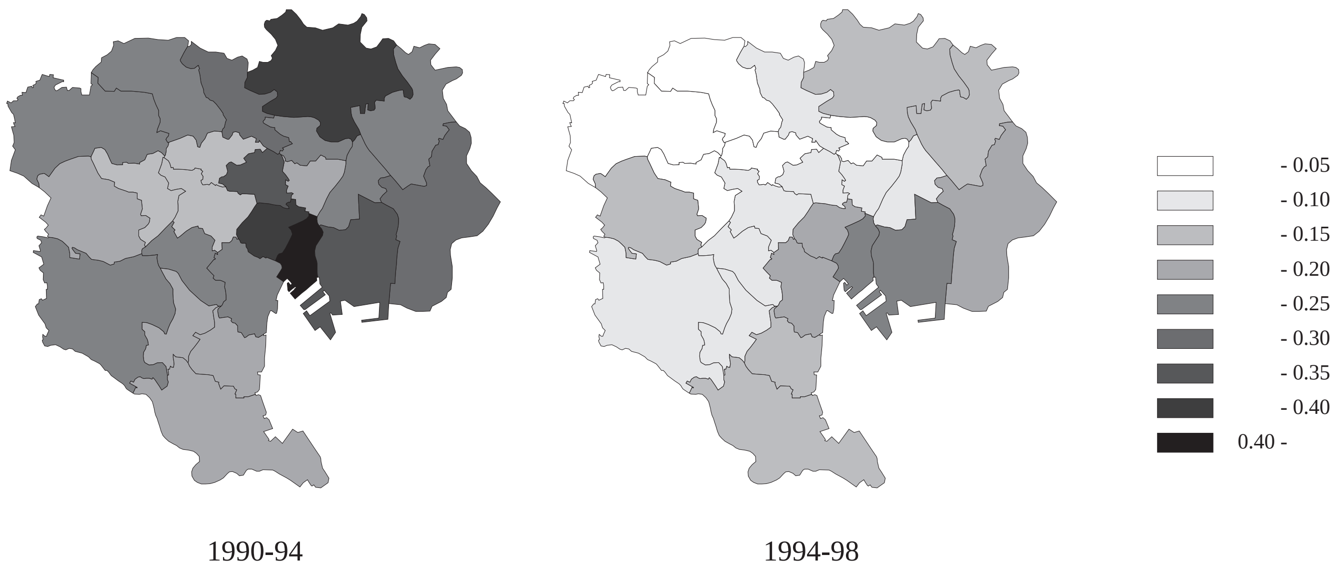


Figure 9

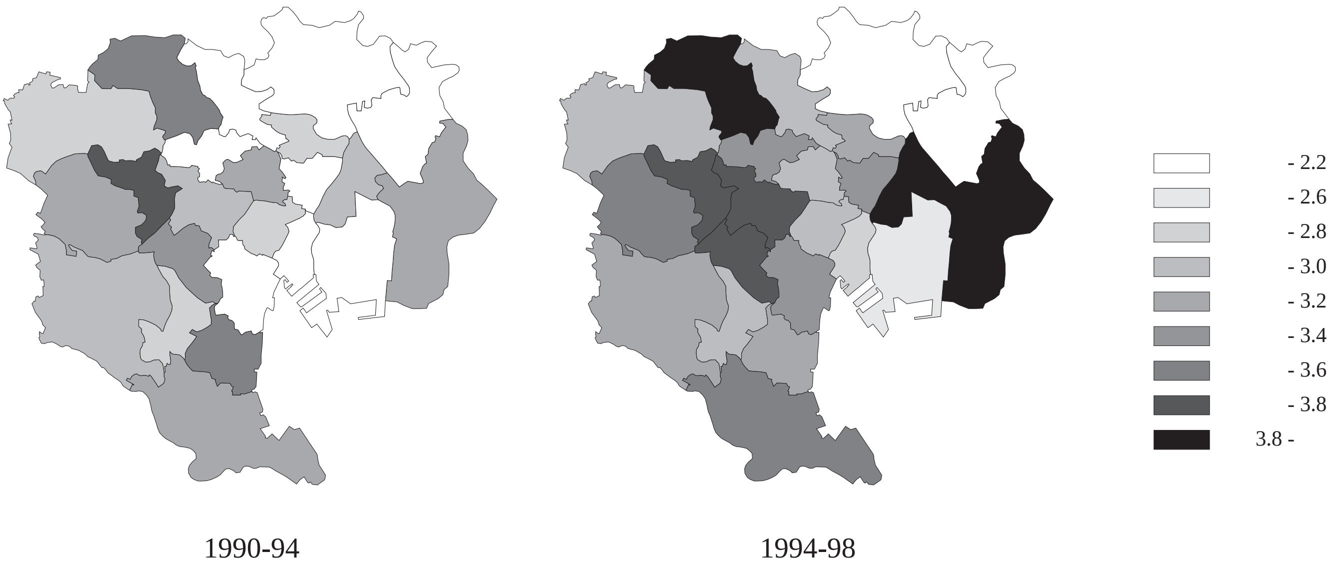
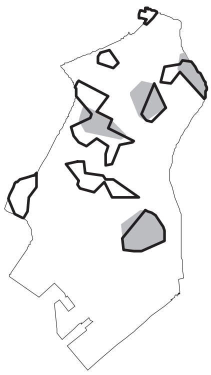


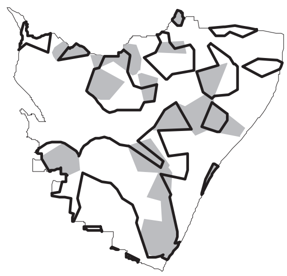
Figure 10



Chuo

total area ratio	1.679
area measure	0.435
event measure	2.083

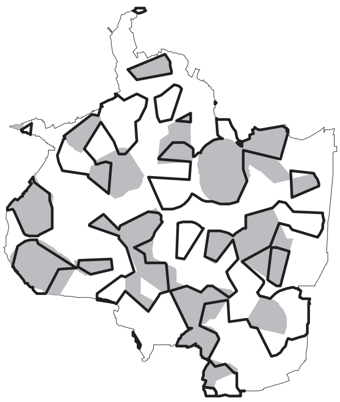
(a)



Taito

total area ratio	1.720
area measure	0.197
event measure	2.385

(b)

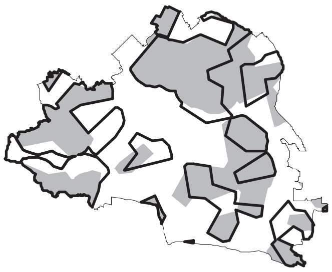


Shinagawa

total area ratio	1.308
area measure	0.199
event measure	3.424

(c)

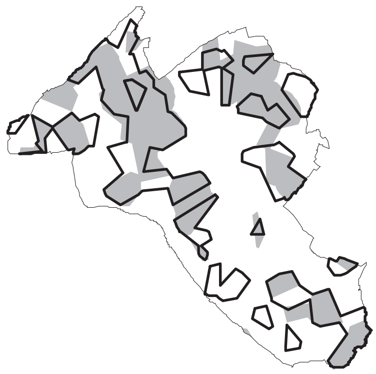
Figure 11



Bunkyo

total area ratio	1.019
area measure	0.074
event measure	2.828

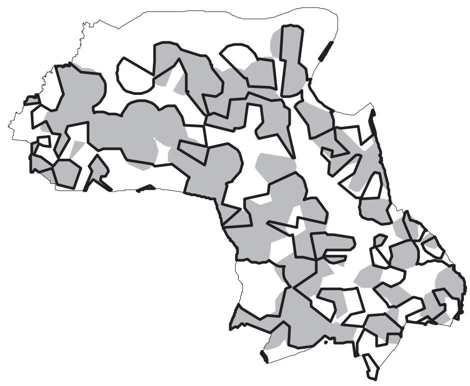
(a)



Shibuya

total area ratio	1.020
area measure	0.093
event measure	3.677

(b)



Itabashi

total area ratio	0.958
area measure	0.040
event measure	4.375

(c)

Figure 12

		all chains			major chains			small chains		
		1990	1994	1998	1990	1994	1998	1990	1994	1998
number of stores		2069	2757	3378	683	1213	1484	1386	1544	1894
total market area	[km^2]	431.2	461.2	481.1	144.4	213.0	231.6	286.8	248.2	249.5
average market area	[km^2]	0.204	0.167	0.142	0.211	0.176	0.156	0.207	0.161	0.132

Table 1

		1990	1994	1998	90-94	94-98
number		414	447	498	1.08	1.11
total area	[km^2]	144.4	213.0	231.6	1.48	1.09
average area	[km^2]	0.349	0.477	0.465	1.37	0.98

Table 2

	total area ratio		area measure		event measure	
ward	90-94	94-98	90-94	94-98	90-94	94-98
Chiyoda	1.409	1.631	0.378	0.195	2.615	2.857
Chuo	1.679	1.247	0.435	0.207	2.083	2.700
Minato	1.883	1.278	0.242	0.158	2.320	3.267
Shinjuku	1.522	1.020	0.130	0.051	2.875	3.674
Bunkyo	1.776	1.019	0.311	0.074	3.192	2.828
Taito	1.720	0.932	0.197	0.063	2.385	3.333
Sumida	1.422	1.310	0.241	0.092	2.875	3.933
Koto	1.342	1.314	0.318	0.220	2.211	2.568
Shinagawa	1.308	1.065	0.199	0.106	3.424	3.146
Meguro	1.672	0.965	0.180	0.060	2.622	1.854
Ota	1.429	1.005	0.186	0.116	3.189	3.426
Setagaya	1.502	0.983	0.217	0.094	2.958	3.027
Shibuya	1.538	1.020	0.249	0.093	3.261	3.677
Nakano	1.218	1.151	0.117	0.025	3.946	3.611
Suginami	1.219	1.101	0.163	0.100	3.200	3.574
Toshima	1.581	1.152	0.112	0.020	2.349	3.260
Kita	1.621	1.183	0.270	0.068	2.324	3.000
Arakawa	1.390	1.432	0.207	0.049	2.704	3.115
Itabashi	1.582	0.958	0.232	0.040	3.561	4.375
Nerima	1.512	1.034	0.207	0.050	2.768	2.965
Adachi	1.705	1.117	0.361	0.143	2.237	2.371
Katsushika	1.205	1.245	0.250	0.121	2.245	2.321
Edogawa	1.378	1.089	0.290	0.157	3.022	3.935
total	1.475	1.087	0.208	0.069	2.818	3.193

Table 3