



Jul 1st, 12:00 AM

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Simulation study on spatial and temporal changes of factories in an industry district

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Abstract: Factories or plants are built or dismantled for various complex reasons. Understanding the construction and dismantlement processes of factories is one of complicated economic problems. The present article has two purposes: one is to explore the spatial and temporal changes of factories at Hamamatsu city in Japan, and the other is to represent the spatial and temporal changes by a simple simulation model. The time dependence of factory number can be classified into two periods. Before the collapse of Japanese stock market (1990), the number of factories increases smoothly. On the contrary, after the collapse, it rapidly decreases. The spatial structures of factories are statistically analyzed by auto-correlation. It is found that the factories more or less form aggregated or crowded structures. When the industrialization is not yet fully developed, the aggregation is very strong. In contrast, just before the collapse (in “bubble period”), the factories nearly form a random distribution rather than aggregation. After the collapse, they form slightly aggregated pattern. Such a profile is similar to that of biological population dynamics. We illustrate that the construction and dismantlement processes of factories can be qualitatively explained by the contact process which is a simple ecological model. Moreover, we discuss the relation between the distribution of factories and the Just-in-Time system in Hamamatsu industry.

Keywords: spatial and temporal changes of factories; degree of factory aggregation; contact process; Just-in-Time system.

1. INTRODUCTION

Factories are built by various social reasons, such as economic growth and increase of consumer's wealth (Weber, 1929; Harris, 1954; Ullman, 1956). Geographical location of factory is also determined by many factors; examples are transportation cost, situations of consumers and laborers, supplying power, and some political or historical reasons. Therefore, it is difficult to explore the causal mechanism of factory distributions. Instead of reasoning, we explore the phenomenal features of factory distribution with the use of spatial simulation models. The present article has two purposes: 1) we report spatial and temporal changes of factories in Hamamatsu, and 2) we explain such a process by a simple lattice model.

Hamamatsu is one of major industrial cities in Japan (Shizuoka Tiiki-gakkai, 1996; Hamamatsu Kikakushitsu, 1954), and located near the middle of Japan (Fig. 1). There are three major companies; Honda and Suzuki motor companies and Yamaha Co. They are very famous as motor companies in the world. In Hamamatsu, new factory tends to be built near existing factories. This is convenient for cutting the costs in transportation and various managements. In particular, Japanese motor makers tend to form aggregation, since major companies introduced the so-called “Just-in-Time (JIT)” system which is first introduced by Toyota Corporation (Sheard, 1983; Estall, 1985). A parent company orders the parts of products (cars or motor cycle) to many subcontractors. According to various demands, the parent company adjusts the production. Many parts are collected and put together, only when they are needed. Hence, parent companies have very few warehouses. By the aggregation of parts subcontractors; physical distribution cost can be reduced. Recently, JIT

system becomes more flexible, so that the aggregation of factories seems somewhat reduced (Nojiri, 2005; Mair, 1992).

Our research area is a rectangle of 18km 24km as displayed in Fig. 1 (b). Real data on the spatial temporal changes are displayed in Fig. 2 (Hamamatsu Chamber of Commerce and Industry, 2006; Hamamatsu Kikakusitsu, 2006). Here each plot represents the center location of each factory. From Fig. 2, we notice the crucial effect of the collapse of Japanese stock market. Near 1990 the stock market crashed, and the values of real estates declined sharply. The time dependence of factory number can be classified into two periods. Before 1990, the number of factory increased smoothly. On the contrary, after the collapse of stock market, it decreased rapidly.

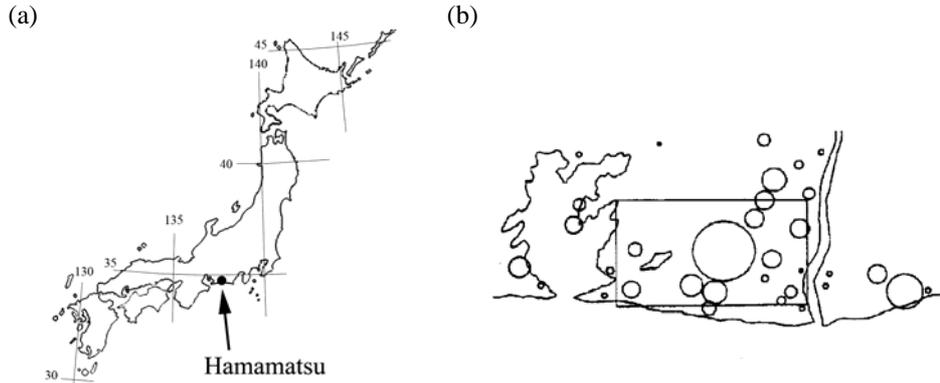
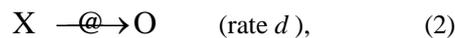
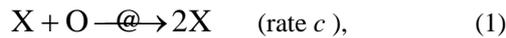


Fig. 1. (a) Location of Hamamatsu. (b) Research area (Hamamatsu Chamber of Commerce and Industry, 1951).

Geography of factories has been studied intensively by many authors (Dacey, 1962; Harvey, 1969; Scott, 1988; Sugiura, 2003). The clumping behavior in factory structure or the formation of “factory district” has been pointed out in relation to ecological distribution (King, 1962; Burton, 1963; Haggett, 1965). In these studies, auto-correlation is adopted as a statistical approach (Schaefer, 1953; Clark and Evans, 1954). In the present paper, we also apply the auto-correlation. However, we use a lattice square: All data of Fig. 2 are once redrawn on the lattice space. After such a replacement, we measure the auto-correlation. This is because our purpose is to represent the dynamics of factories by a simple lattice model.

2. CONTACT PROCESS (CP)

In order to represent the dynamics of factories, we apply “contact process” on a two-dimensional lattice. The contact process (CP) was first introduced by Harris (1974) as a model of infectious disease. CP has been extensively studied from mathematical (Harris, 1974; Liggett, 1985), physical (Katori & Konno, 1991; Marro & Dickman, 1999) and ecological (Miyazaki et al, 2006; Itoh et al, 2004) aspects. Each lattice site takes one of two states: empty (O) or occupied (X) by factory. Interactions for CP are defined by



The reaction (1) means the construction process of factories; a new factory is build at the neighboring site of existing factory. The parameter c thus denotes the construction rate of factory. On the other hand, the reaction (2) denotes the dismantlement process, and the parameter d is a dismantlement rate. In the original model (Harris, 1974), the site X (or O) meant the infectious (or healthy) person; the reactions (1) and (2) respectively represented the infection and healing of disease.

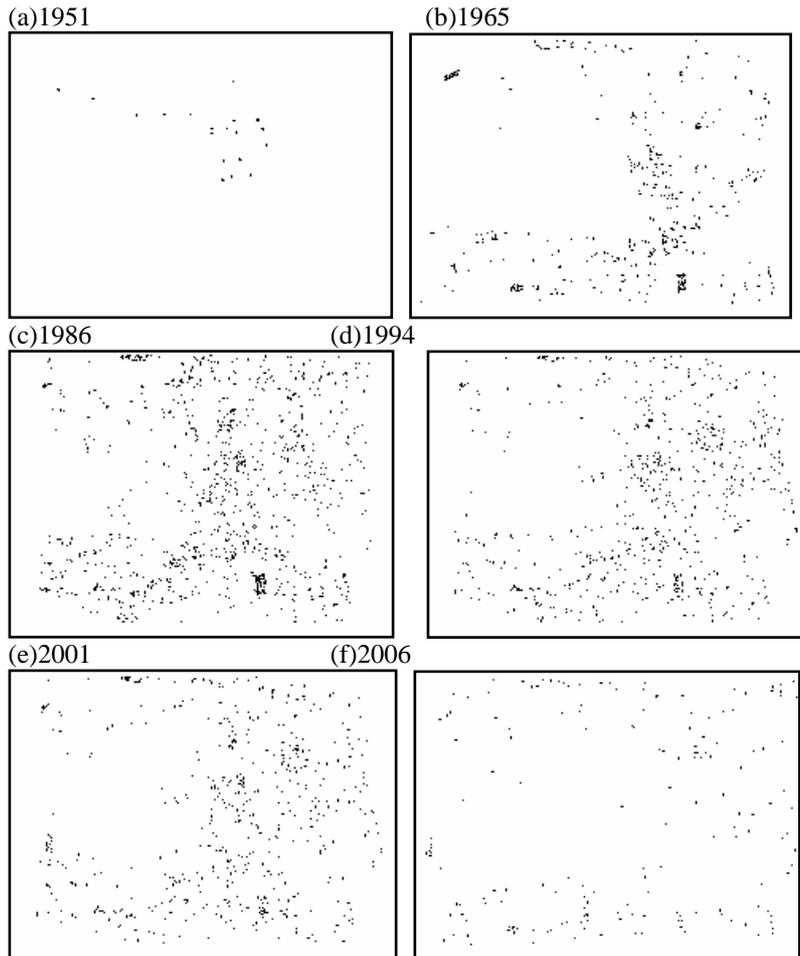


Fig. 2
Spatial and temporal changes of factories in Hamamatsu. Each plot represents the centre of factory which has more than three workers

In the field of ecology, CP is also used; in this case, the site X means an individual or the occupied site by biospecies. The reactions (1) and (2) respectively represent the birth and death processes. The site O denotes empty. The parameter c and d are birth and death rates, respectively.

Simulation method for CP is as follows:

- 1) Initially, we distribute factories on the lattice. Each lattice site is one of two states; namely occupied (X) and empty (O) sites.
- 2) The reactions (2) are performed in the following two steps:
 - (i) We perform two-body reaction (1). Choose one lattice site randomly, and then randomly specify one of neighboring sites. If the pair of sites are (X, O), then O is changed into X.
 - (ii) We perform one-body reaction (2). Choose one lattice point randomly; if the site is occupied by X, the site will become O by the rate d .
- 3) Repeat the above step 2) T times, where T is the total number of lattice points. This is called the Monte Carlo step (MCS) (Tainaka, 1988). In other words, time in simulation is measured by the unit of MCS.
- 4) Continue the step 3) until an adequate time.

The initial structure is not so important, since the system evolves into a stationary state. The density (number) of X in the final (equilibrium) state depends on both parameters c and d . When the value d (or c) is increased (or decreased), then the final density decreases. According to the previous studies, the final density is uniquely determined by the ratio d/c (Harris, 1974; Marro & Dickman, 1999). Namely, CP can be represented by a single parameter. For this reason, in the present paper, we fix the value of c ($c=1$), and change parameter d .

3. METHODS

Lattice representation

We first represent the actual data in Fig. 2 by the use of a lattice. The rectangle of 18km × 24km is divided into the mesh of 180 × 240. The total number of lattice sites is thus given by 180 × 240 sites, and each site corresponds to a 100-meter square. The state of a single lattice site takes one of two states; either occupied (X) or empty (O). The site X means there is at least one factory in the square. In contrast, the site O means the absence of factory. Overall profile in the lattice representation is almost the same as spatial pattern displayed in Fig. 2.

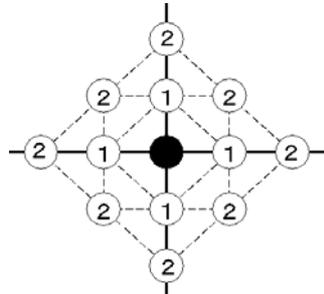
Statistical method: Auto-Correlation

We analyse the spatial pattern by the use of correlation function. Let $F(r)$ be the auto-correlation, where r is the distance between a pair of lattice sites. The distance r takes discrete values as shown in Fig. 3. The shortest distance ($r=1$) means the nearest (one-step) neighbour, and $r=2$ means the two-step distance. The distance $r=1$ is most important, since the correlation function is usually a decreasing function of distance. The auto-correlation $F(r)$ means the conditional probability. Assume that there is X at a lattice site A (centre site in Fig. 3), then $F(r)$ is defined by the probability finding X at another site B, where B locates at the distance r apart from the site A. If the distribution is completely random, $F(r)$ is equal to the overall density (the probability finding X at a site). Hereafter, the auto-correlation is scaled (divided) by the overall density; in this way, we can set $F(r) = 1$ for the random distribution. According to the value of auto-correlation, the spatial structure of factory is classified as follows (Tainaka and Fukazawa, 1992):

- (a) $F(r) > 1$: aggregated (clustering) pattern
- (b) $F(r) = 1$: random distribution
- (c) $F(r) < 1$: uniform (dispersed) pattern

Fig. 3

Schematic illustration of distance r . The numerals in circles denote the distance (r). The nearest (one-step) neighbour is represented by $r=1$, and the two-step neighbour corresponds to $r=2$.



4. RESULTS

4.1 Statistical Results

From the spatial and temporal data of factories at Hamamatsu, we obtain statistical results. In Fig. 4, the time dependences of both density (number) and degree of clumping are displayed. It is found from Fig. 4 that the degree of clumping was crucially influenced by the collapse of stock market (near 1990). Just before the collapse (in “bubble period”), the factories nearly followed a random distribution rather than aggregation. In contrast, in the early stage of industrialization (1951), the distribution of factories showed an extreme aggregation tendency. Almost all factories were clustered in local area (“factory district”). However, as the number of factory had increased during the bubble economic stage, the degree of clumping had decreased almost to be random. After the collapse of bubble, the clumping tendency returned. The value of clumping degree in 2006 was much smaller than that in 1951. The present-day factories are not so aggregated compared with the early stage. This may be associated with the fact that JIT system became more flexible than the early stage (Nojiri, 2005; Linge, 1991). In summary, when the industrialization is not yet fully

developed, the aggregation is very strong. In contrast, when the density of factories is high (bubble period), the factories nearly distribute randomly. After the bubble, the degree of clumping slightly recovered.

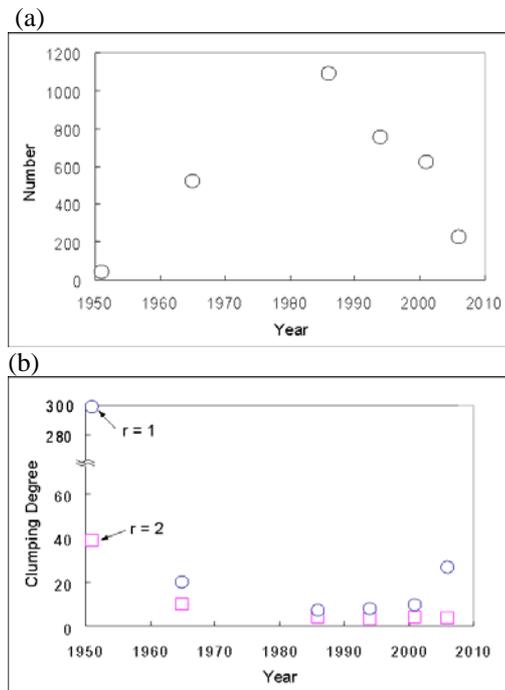


Fig. 4
The statistical results of factories in Hamamatsu. (a) Number of factories, and (b) degree of clumping (auto-correlations) $F(r)$, where $r=1, 2$. If the distribution of individuals is random, then $F(r) = 1$. In the early stage of industrialization (1951), the aggregation is found to be very strong. Just before the collapse (in “bubble period”), the factories nearly form a random distribution rather than aggregation

4.2 Simulation Results

The clustering profile of factories is very similar to that of biological individuals. We represent the construction and dismantlement processes by the contact process. The parameter value of d is changed as shown in Fig. 5. Here we assume the linear time dependence (straight lines); the slope of the line is positive before the collapse of stock market (1990), while it is negative after 1990. The value of d is determined as the density profile agrees with actual data in Fig. 4(a).

In Fig. 6, the simulation results are shown. It is apparent that the time dependence of density in Fig. 6(a) is almost the same as that in Fig. 4(a). The important point is the outcome in Fig. 6(b). The profile of clumping degree in Fig. 6(b) is similar to the real data in Fig. 4(b). When the total number of factories is small, the aggregation is strong. Figure 7 illustrate a typical spatial pattern in the case of low density. It is found that factories are densely aggregated. In contrast, when the density of factories is high, the factories nearly form a random distribution. In particular, at the bubble period, the factories nearly form a random distribution. These characteristics can be represented by the simulation of contact process.

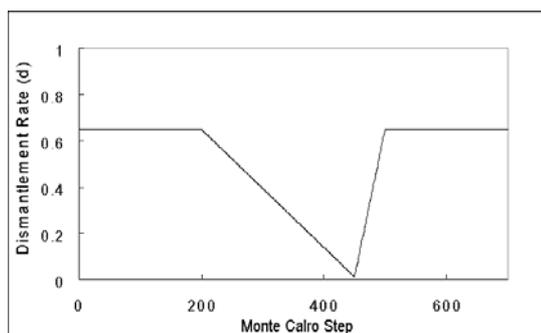


Fig. 5
The assumption of value of parameter d . It is known for the contact process that we can put $c=1$ without the loss of generality.

5. DISCUSSION

We study dynamics process of factories at Hamamatsu city in Japan. The time dependence of factory number can be classified into two periods. Before the collapse of stock market (1990), the number of factories increases smoothly. On the contrary, after the collapse, it rapidly decreases. The spatial structures of factories are statistically analyzed by auto-correlation (clumping degree). It is found that the factories more or less form aggregated or crowded distribution. When the total density of factories is low, the aggregation is found to be strong. In contrast, just before the collapse (bubble period), the spatial pattern of factories is almost random.

We represent the construction and dismantlement processes of factories by the contact process which is a simple simulation model. The time dependence of clumping degree (Fig. 6(b)) has the similar profile to the real data in Fig. 4(b). Both characteristics of density and auto-correlation can be explained by the use of a single parameter (ratio or dismantlement rate). The values of auto-correlation obtained from simulations (Fig. 6(b)) agree well qualitatively with the actual data (Fig. 4(b)). Note that the fact that the absolute values does not match with the simulated values is not important, because the absolute density of factories depends on the sizes of cells and study areas. If we consider larger area than that in Fig. 1(b), then the density (clumping degree) should be decreased (increased). This is because the factory density outside Hamamatsu is much less than that in Hamamatsu. The important point is the relative changes of clumping degree or density in time

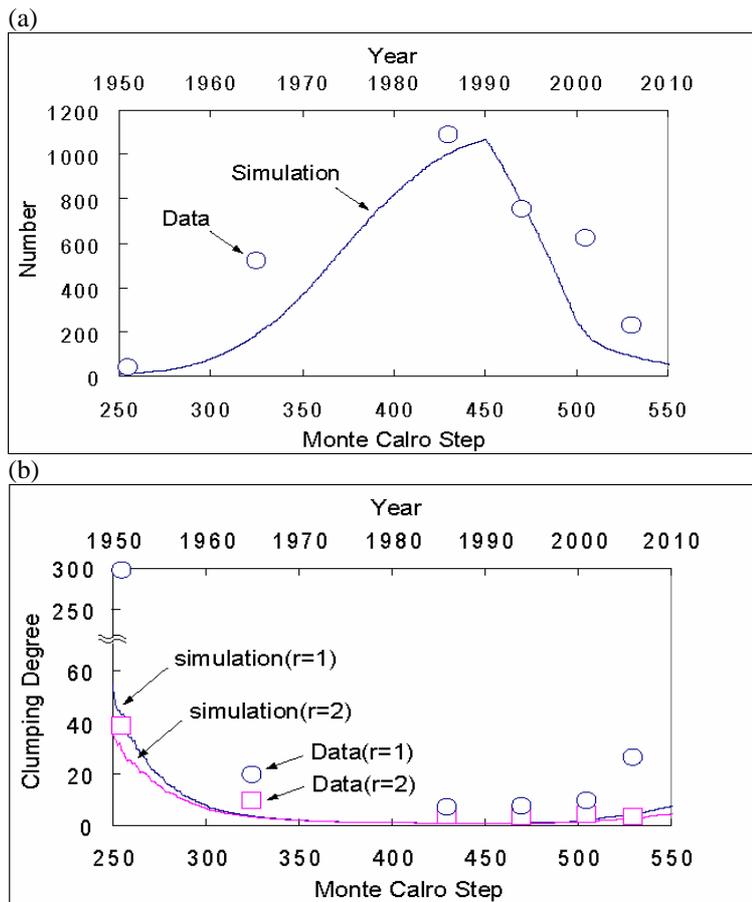


Fig. 6

The results of simulation. (a) Number of factories, and (b) degree of clumping. The actual data are represented by plots which are the same as in Fig. 4.

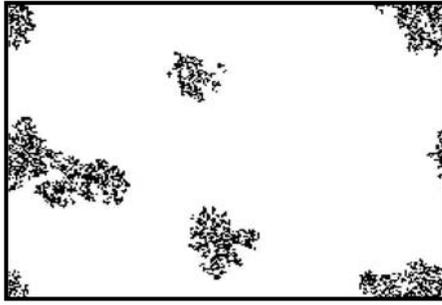


Fig. 7
Snapshots of typical spatial patterns at $t = 540$. Black and white sites denote occupied and empty site of factory.

We discuss the reason why the aggregation of factories is naturally formed. In Hamamatsu city, there are three major companies: Honda and Suzuki motor companies and Yamaha Co. They are all very famous as a motor company in the world. When the industrialization is not yet fully developed (1951), the aggregation is found to be very strong. Such an aggregated formation of factories (factory district) may be associated with the construction process of factory. Namely new factory tend to be built near existing factories [the reaction (1)]. This is convenient for cutting the costs in transportation (Estall, 1985) and information exchange (Dyer, 1996).

Finally, we discuss the relation between degree of clumping and just-in-time (JIT) system. In 1950's, Toyota motor companies introduced JIT system. A decade later, JIT had been adopted by the motor companies in Hamamatsu (Sheard, 1983). Due to JIT system, physical distribution costs could have been reduced. Our results indicate that the degree of clumping is strongest, when the industrialization is not yet fully developed (1951). During the bubble period, the needs for transportation cost-cuts were reduced, due to high demands for products. After the collapse of markets in 1990, the distribution of factories became aggregated (clumped) again, but a much lesser degree. This might be due to the fact that the characteristics of JIT have been diversified due to the severe evaluation by consumers after the bubble stage (Nojiri, 2005). Thus the temporal changes in the distribution of factories in Hamamatsu might be explained by the temporal economic changes and the characteristics in JIT systems. Our results may suggest that the causal mechanisms of aggregation tendencies in industry may be well simulated by a contact process in the lattice model.

ACKNOWLEDGMENTS

The authors wish to thank Mr. Taro Hayashi for his help in simulations.

REFERENCES

- Burton, I., The Quantitative Revolution and Theoretical Geography, *Canadian Geogr.*, 7, 151-162, 1963.
- Clark, P.J. and F.C. Evans, Distance to nearest neighbor as a measure of spatial relationship in populations, *Ecology*, 35, 445-453, 1954.
- Dacey, M.F., "Analysis of Central Place and Point Patterns by a Nearest Neighbor Method" in Norborg, K. ed. "Proceedings of the I.G.U. Symposium in Urban Geography. Lund. 1960", *Lund Studies in Geography*, B. Vol. 24, CWK (Gleerup, Lund) 55-75, 1962.
- Dyer, J.H., Specialized supplier networks as a source of competitive advantage: evidence from the auto industry, *Strategic Management Journal*, 17, 271-291, 1996.
- Estall, R.C., Stock control in manufacturing: the Just-in-Time systems and its locational implications, *Area*, 17, 129-133, 1985.
- Haggett, P., Location Analysis in Human Geography, London, Edward Arnold, 1965.
- Hamamatsu Kikakushitsu, Hamamatsu-City Statistics Book (Hamamatsu-City Group Handbook before 1951), Hamamatsu (in Japanese), 2006.

- Hamamatsu Kikakushitsu, Hamamatsu Developing History, Hamamatsu (in Japanese), 1954.
- Hamamatsu Chamber of Commerce and Industry, Hamamatsu Shoko Meikan (in Japanese), 1951.
- Hamamatsu Chamber of Commerce and Industry, Hamamatsu Shoko Meikan (in Japanese), 2006.
- Harris, C.D., "The Market as a Factor in the Localization of Industry in the United States", *Annals of the Association of America Geographers*, 44, 315-348, 1954.
- Harris, T.E., Contact interaction on a lattice, *Ann Prob.*, 2, 969-988, 1974.
- Harvey, D., *Explanation in Geography*, London, Edward Arnold, 1969.
- Itoh, Y. Tainaka, K. Sakata, T. Tao, T. and Nakagiri, N., Spatial Enhancement of Population Uncertainty near the Extinction Threshold, *Ecological Modelling*, 174, 191-201, 2004.
- Katori, M. and Konno, N., Upper bounds for survival probability of the contact process, *J. Stat. Phys.*, 63, 115-130, 1991.
- King, L.J., A Quantitative Expression of the Patterns of Urban Settlement in Selected Areas of the United States, *Tijdschrift voor Economische en Sociale Geografie*, 53, 1-7, 1962.
- Liggett, T. M., *Interacting particle systems*, New York, Springer-Verlag, 1985.
- Linge, G.J.R., Just-in-time: more or less flexible?, *Economic Geography*, 67, 316-332, 1991.
- Mair, A., Just-in-Time manufacturing and the spatial structure of the automobile industry: lessons from Japan, *Tijdschrift voor Economische en Sociale Geografie*, 83, 82-92, 1992.
- Marro, J. and Dickman, R., *Nonequilibrium phase transition in lattice models*, Cambridge, Cambridge Univ., Press, 1999.
- Miyazaki, T. Tainaka, K. Togashi, T. Suzuki, T. and Yoshimura, J., Spatial coexistence of phytoplankton species in ecological timescale, *Popul. Ecol.*, 48, 107-112, 2006.
- Nojiri, W., Review of studies on Just-in-Time in economics and economic geography, *Memoirs of Momoyama Gakuin University*, 31, 21-32, 2005.
- Scott, A.J., *Metropolis: From the Division of Labor to Urban Form*. Berkeley and Los Angeles, University of California Press, 1988.
- Schaefer, F. K., Exceptionalism in Geography: A Methodological Examination, *Ann. Assoc. Amer. Geogr.*, 43, 226-249, 1953.
- Sheard, P., Auto production systems in Japan; organizational and locational features, *Australian Geographical Studies*, 21, 49-68, 1983.
- Shizuoka Tiiki-gakkai, *Shizuoka no tiikisangyou (Area's Industries of Shizuoka)*, Tokyo, Kyoritu (in Japanese), 1996.
- Sugiura, Yosio, *Tiri Kukan Bunseki (Spatial Analysis in Geography)*, Tokyo, Asakura (in Japanese), 2003.
- Tainaka, K., Lattice model for the Lotka-Volterra system, *J. Phys Soc. Jpn*, 57, 2588-2590, 1988.
- Tainaka, K. and Fukazawa, S., Spatial pattern in a chemical reaction system: prey and predator in the position-fixed limit, *J. Phys. Soc. Jpn*, 61, 1891-1894, 1992.
- Ullman, E.L., "The Role of Transportation and the Bases of Interaction" in Thomas, W.L. (ed.), *Man's Role in Changing the Face of the Earth*, Chicago, 1956.
- Weber, A. and Friedrich, C.J. (ed.), *Alfred Weber's Theory of the Location of Industry*, Chicago, 1929.