CHANGE OF URBAN STRUCTURE

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摘　要

都市分散化與次中心的形成是當代都市結構的趨勢。美國近代各大城市資料顯示明顯的就業郊區化與人口分散化的現象。理論上，次中心的形成因素主要是聚集經濟的影響、勞動力接近度、交通條件以及市中心負的聚集經濟外部效果。

本文目的在由推導之都市成長模型，探討次中心形成的主要因素：(1)聚集經濟的變化是如何影響次中心的形成，以至於影響都市結構。(2)交通成本在次中心形成與都市結構變化中所扮演的角色。

研究結果顯示：(1)次中心的形成與交通成本的演化相關。(2)當交通成本低於某臨界值，交通成本越低，都市人口密度變化率(population density gradient)的絕對值越小；反之，當交通成本高於某臨界值、交通成本越高，都市人口密度變化率(population density gradient)的絕對值越小。這代表當交通成本頗低時，交通成本越低，人口越分散化；當交通成本頗高時，交通成本越高，都市間人口數越一致。(3)交通成本會影響聚集經濟的分佈型態，而聚集經濟分佈型態的改變與次中心的成長之間具有高度的相關性。

Abstract

Recent research shows that subcenters are becoming important part of urban structure. The formation of subcenters are theoretically understood based on agglomeration economies, labor-force accessibility, transportation nodes, and negative agglomeration effect of CBD. The purpose of this paper is to investigate how the change of agglomeration economies affects the growth of subcenters; how commuting cost affects urban structure through agglomeration economies. The results show that when commuting cost is less than a critical level, the smaller the commuting cost the less the absolute value of population density gradient. Once the commuting cost is larger then the critical level, the larger the commuting cost the less the absolute value of the population density gradient. Besides, the level of commuting cost will affect the distribution of agglomeration economies. Finally, we find that the growth of subcenters is highly related to the change of agglomeration economies distributions.

I. Introduction

Recent research shows that contemporary metropolitan areas in U.S. are characterized by decentralized patterns of employment, and job locations in metropolitan areas are increasingly dispersed. For the Los Angeles CMSA, 19 percent of workers commuted

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to centers in 1970, 17 percent worked in centers in 1980 and 12 percent worked in centers in 1990. It shows that firms increasingly moving away from centers into suburbs. However, these decentralization of urban areas is not uniformly distributed into suburb of employment and population. Instead, employment and population are dispersed from central business center into several subcenters. In other words, cities are undergoing an evolution from single-centers to multicenters structures in which employment concentrate in several subcenters in addition to the central business district (CBD).

The empirical analysis of the metropolitan Los Angeles region by Giuliano and Small (1991b) and Gordon, Richardson and Wong (1986) found that population has continued to disperse in the 1970s, and the polycentric model of population distribution fits LA much better than the monocentric model. Giuliano and Small (1991b) investigated employment subcenters in the Los Angeles region in 1980. They found a surprising dominance of downtown Los Angeles and three large subcenters. Two-thirds of the region's employment is outside 32 centers they identify. These empirical works confirm the Los Angeles region was undergoing the revolution of suburbanization from monocentric form to polycentric configuration.

In fact, subcenters become essential in urban structure not only in Los Angeles region but also in other places. Theoretical understanding, the formation of subcenters are based on the follows[1]: first, agglomeration effects; second, labor force accessibility; third, transportation facilities; fourth, negative agglomeration effects of the main center such as land scarcity, congestion. The phenomenon of firms tending to concentrate in center or subcenters is explained by the positive effect of "agglomeration economies". That implies that concentration of firms enables them to save commuting cost, to access information and labor force easily; furthermore, to take advantage of consumers' comparison-shopping and multipurpose-trip economies. Besides those positive effects, industries also generate some negative effect like congestion and pollution by gathering together. The aggregate result from positive and negative effects is called net agglomeration effect. Agglomeration economies and access to transport nodes result in the formation of subcenters. In addition, saving costs for land and labor inputs is also the motives for industries moving outward instead of concentrating in a CBD.

The formation of subcenters and the suburbanization trend have been the major structure of contemporary urban form; also, both transport cost and agglomeration effects are essential in explaining the form of subcenter and decentralization. It is quite important to understand how transport cost and agglomeration effects affect the urban structure.

[1] Fugita and Ogawa (1982), Kim (1983), Wieand (1987), Sasaki (1990).

However there is lack of related empirical works to systematically analyze the features of these influence. Simulation would be a very suitable way to fulfill this purpose due to the constraint of available data and model.

The basic urban model is formulated by Alonso (1964); it is limited in static state and with only one employment center at fixed location. This model has been generalized by various studies through including production, transport, and housing. (Mills, 1967; Muth, 1969; Fujita, 1989). However, the limit of line-city and the static assumption is still remained in these later studies; these assumptions constrain the explaining power of the model. Allen and Sanglier (1978) developed a dynamic growth model, which is derived from a biological evolution model, to explain the growth of region. Pumain (1987) and Straussfogel (1991) applied this model to do empirical analysis. This kind of model allows more than one centers in the region; also, it is dynamic rather than static. However, lack of land rent and economic foundation is the major shortcoming of this kind of model. Chen (1996) applies the basic land use theory into a dynamic general equilibrium framework to derive a nonlinear dynamic urban growth model. It allows multicenters in the region, and endogenizes population, employment, land rent and agglomeration effect. Furthermore, this model is derived based on a microeconomics framework. Basically, Chen's model is an extension of Alonso (1964), and use similar logistic growth model as Allen and Sanglier (1978) in dynamic states. The models of Alonso (1964) and Allen and Sanglier (1978) do not contain the agglomeration effect; also land rent is not determined inside the system. Simulations of Allen's model are performed in Pumain (1987) and Straussfogel (1991) to present the geographical formation of subcenters. There is no analysis of the effect from transport cost and agglomeration effect on the urban forms or structure. Chen (1996) only introduce the derived model and shows how it can work in simulation; there is no systematic analysis about transport cost and agglomeration effects either. It is promising to simulate this derived model to examine the influence of the change of transport cost on urban structure. It would also be very helpful to investigate how the formation of subcenters related to the agglomeration effect through simulation.

The purpose of this paper is to investigate how the change of agglomeration economies influences the growth of subcenters; how the commuting cost affects urban structure through agglomeration economies. Empirical simulations will be performed for these purposes based on the dynamic urban growth model derived by Chen (1996). This model is developed according to the basic land use theory: optimal location choice for both household and firm. This paper also examines what kind of characteristic in urban structure this ideal location choice theory in urban economics will lead to. We focus on the transport cost and net agglomeration effect.

Section 2 briefly describes the model (see Chen (1996) for detail), and section 3 shows the simulation regarding to the effect of change in commuting cost on urban structure and the relation between net agglomeration effect and growth of subcenter. The conclusion is in section 4. We find that when commuting cost is less than a critical level, the smaller the commuting cost the less the absolute value of population density gradient. Once the commuting cost is larger then the critical level, the larger the commuting cost the less the absolute value of the population density gradient. Besides, the level of commuting cost will affect the distribution of agglomeration economies. Finally, the growth of subcenters is highly related to the change of agglomeration economies distributions.

2. The model

This dynamic urban growth model includes three kinds of actors: household, firms, and land developers. Households, who supply of labor and demand for commodities, choose their residential location to maximize utility subject to budget constraint. Firms, who produce commodities and create employment opportunities, choose plant site to maximize their profit. Similarly, land developer also maximize their profit to choose land to develop. Geographically, this model assumes multiple zones in the region. It is two-dimensional and dynamic; thus, it allows policenters and urban growth. Households' utility function is a function of commodity and land; the budget constraint includes price of commodities, land and also working commuting cost. Similarly, firm's production function includes net agglomeration effect, labor and land; the cost function composes of commodities price, land price and transport cost. This constraint optimization problem is solved through a general equilibrium framework. Moreover, the indirect objective functions are applied into the discrete logit models to form the location choice probabilities of both household and firm. Finally, to apply these location choice probabilities into the biologically logistic growth model to measure the growth of population and employment.

In static equilibrium, household's residential choice depends on the employment opportunities, land rent, commuting costs and other living costs; firms' plant site decisions depend on the producing costs, land rent, demand for their product and the net agglomeration effect. Land rent is determined by demand and supply of the developed land.

Dynamically, firms are in the process of relocating during the same time interval as residents. The location decisions of both households and firms are interacted with each other; furthermore, they are also influenced by the change of land rent and net agglomeration effect. In general, household, firm, net agglomeration effect, and land rent are endogenous. Their distributions are interacted with each other simultaneously and dynamically. The study area is a triangular lattice. In this section, we only present major equations in the model. Please see Chen (1996) for the detail explanation and derivations.

The net agglomeration effect is:

$$A_i^k = 1 + \rho^k \bar{J}_i (1 - \psi^k \bar{J}_i), \quad k = E, S \tag{1}$$

$$where \quad \bar{J}_i = \sum_j J_j^k \exp(-\omega_i d_{ij})$$

Variable A_i denotes the net agglomeration effect at zone i; parameter E represents export employment and S represents service employment. Parameter ρ^k represents cooperativity or the economies of scale; parameter ψ^k denotes the negative externalizes saturation effects. Variable J_i represents employment in zone i. Finally, variable $\bar{J}_i$ denotes the sum of the weighted employment at zone i. The weight is a negative exponential function of distance; parameter ω measures the friction of distance. The net agglomeration effect of firms are the aggregate result of positive and negative influences from firms gathering together; it is assumed to be a function of the weighted sum of each zone's employment in the region expressed in equation (1). This net agglomeration function is introduced into the model through firm's production function. It is assumed that firm's production function is the original function times the net agglomeration effect.

The evolution of population is composed of natural change and net immigration. Net immigration is proportional to the potential population growth which is assumed as a function of the difference of the potential population and the existing population.

$$P_{i,t+1} - P_{i,t} = \tau * (P'_{i,t} - P_{i,t}) + \bar{n} * P_{i,t} \tag{2}$$

Variable $P_{i,t}$ represents the population at zone i at time t; $P'_{i,t}$ denotes the potential population. Parameter τ represents the adjustment rate, and parameter $\bar{n}$ is the natural change rate. The potential population ($P'_{i,t}$), which is the maximum population that can be sustained at the locality, is measured by the sum of possible residents in zone i who works in all zones. The possibility for household who works in zone j but lives in zone i is measured by a logit function based on household's utility function.

Similar to population growth, the growth of employment is assumed to be proportional to the gap between the potential employment and the existing employment.

$$J_{i,t+1}{}^{k} - J_{i,t}{}^{k} = \sigma^{k} * (J'_{i,t}{}^{k} - J_{i,t}{}^{k}), \quad k = E,S \tag{3}$$

Variable $J_{i,t}$ represents the employment at zone i at time t; $J'_{i,t}$ denotes the potential employment. Parameter σ represents the adjustment rate. The potential employment ($J'_{i,t}$), which is predicted by the aggregate weighted demand from all the other zones at a given time, is the maximum employment that can be sustained at zone i. It is analogous to zone i's employment carrying capacity at that time. The potential employment of service activities is generated by local demand within the system; rather, the potential employment of export activities is generated by demand outside the region. The demand of employment is measured by the product of a multiplier and the population. Multiplying this employment demand to a relative attractiveness derives the amount of the employment demand that this zone is able to attract. The relative attractiveness is a logic function based on firm's profit function.

Location choices of both household and firm are denoted by choice possibilities measured by the logit model based on the indirect objective function (utility function and profit function). In the dynamic state, this model applies a simple logistic growth model to explain the growth of population and employment.

3. Simulations

Both the residential location behavior of households and plant site location behavior of firms are analyzed in a microeconomic framework. Extensions to a general equilibrium framework (i.e., simultaneous determination of location of both households and firms) and to a dynamic framework is also considered in our model. According to the assumptions this model based on, both households and firms make location decisions to minimize commuting cost. Households choose residential location under the tradeoff of land rent and commuting cost; firms choose plant site under the trade off of land rent, commuting cost of workers, and net agglomeration effect.

We are interested in examining the consequences of the urban structure in terms of population or employment distributions due to the changes of transport cost and the distribution of the net agglomeration effect through simulations. Two kinds of simulation are performed: change of transport cost and the net agglomeration effects.

The study region in the simulation is a rectangular grids including 49 zones as in Figure 4; population and employment are uniformly distributed in the beginning. All zones have the same initial conditions; the only difference between each zone in the beginning is the location. The agglomeration effect depends on the location and industry size of each zone. In the beginning of simulation, net agglomeration effects of both export and service activities are generated by the given values of parameters and the initial values of endogenous variables: population, export employment and service employment. Then, we derive potential export employment and potential service employment. Finally, we calculate potential population from all this information. Once we know the potential population and employment, the change of population, change of service employment and change of export employment from current time period to the next time period are calculated. The values of the variables at next period are the sum of their current values and the changes of those variables. The same processes are iterately repeated.

3.1 Experiment 1

The purpose of this experiment is to find out how does the commuting cost affect the population and land rent distribution. Given all the other parameters and variables the same, each simulation has different value of commuting cost. These simulation is based on the assumption of monocentric model with CBD at the center of region (zone 25). The monocentric density function is popularly assumed as a negative exponential density function as the follows:

$$D_i = D_0 e^{\lambda d_i} e^{u_i}, \quad i = 1,2, \ldots, N. \tag{4}$$

where D_i is the employment density at zone i; D_o and λ are parameters to be estimated from the data by ordinary least square of the natural logarithm of equation (4); d_i denotes the commuting distance or time from zone i to the center. u_i the error term associated with zone i. After taking the natural logarithm of equation (4), we have

$$\ln D_i = \ln D_0 + \lambda d_i + u_i \tag{5}$$

where parameter λ represents the percentage change of density D_i with respect to one unit change of commuting distance d_i. The absolute value of parameter λ is called density gradient. A negative density value of density gradient represents that employment density is decreased as farther from the center. If we replace employment density by the land rent in equation (4) and (5), the density gradient will become the land rent gradient.

Both density gradient and land rent gradient are estimated by the data from each simulation after thirty times iterations. The simulating density gradients at time t=30 given different initial values of unit transport cost is presented in Table 1.

Table 1. Estimated Density Gradient Given different Initial Unit Transport Cost

$$\ln(D_i) = \ln(D_0) + \lambda * d_i \quad (i = 1,...49 \text{ and } j=25)$$

Unit Transport Cost	$\ln(\hat{D}_0)$	$\hat{\lambda}$	D_{25}
	Estimated Intercept	$\lvert\hat{\lambda}\rvert$ is the Estimated Density Gradient	Center Zone's Density
35	10.0348	.0056* (.0020)	23217
20	10.0878	-.0156* (.0021)	23929
10	10.1573	-.0438* (.0028)	24983
8	10.1777	-.0522* (.0031)	25293
5	10.2155	-.0676* (.0037)	25859
3	10.2521	-.0828* (.0042)	26409
2	10.2866	-.0971* (.0045)	27125
1.5	10.3041	-.1044* (.0044)	27687
1	10.2912	-.0990* (.0041)	27378
0.8	10.2753	-.0923* (.0039)	27010
0.6	10.2536	-.0833* (.0036)	26581
0.4	10.2242	-.0712* (.0030)	26073
0.2	10.1744	-.0507* (.0021)	25236
0.1	10.1261	-.0299* (.0071)	24416
0.05	10.0833	-.0112 (.0108)	23595
0.04	10.0799	-.0097 (.0106)	23558
0.03	10.0871	-.0150* (.0052)	23760
0.01	10.0614	-.0050* (.0002)	23335

Notes:
Standard errors are in parentheses
*Estimate is statistically significant at 0.05 level, 2-sided test.

In this table, all estimated slope (λ) is negative except one (when transport cost is fairly high:35). This indicated that population distributes highly in the center and then with a decreasing density away from the center. When transport cost equals 0.01, the estimated density gradient The values of estimated density gradient and intercept increase as the value of transport cost increases from 0.01 to 1.5; they start decreasing when transport cost is getting larger than a value of 2. A larger density gradient implies a faster decrease in density as away from the center, which denotes a steeper center in the region. On the contrary, a relatively smaller density gradient implies a flatter distribution.

The change of distribution caused by the value of transport cost is in different direction separated by a turning point of transport cost. The turning point where the gradient and constant term change from increasing to decreasing is defined as a critical level of commuting cost. In this experiment the critical level is 1.5. When the commuting cost is greater than 1.5, the transportation cost is so high that it becomes hard to communicate between central zone and suburban zones. The center is loosing its accessibility to the whole region; consequently, it can no longer attract as many residents as before. In addition, the suburban zones are too far from the center to be included in the same urban area ,and therefore the centralization feature of the urban area is getting vague as the commuting cost is above the critical level and gets higher.

If the commuting cost is equal to or less than the critical level, it is possible to commute throughout the whole region. Since every zone has the same initial conditions except for the location, population and activity tend to concentrate to the center owing to the accessibility advantage. Both density gradient and intercept decrease with commuting cost when commuting cost is below 1.5. This is because that as the commuting cost gets lower, the advantage from the location becomes smaller. When the difference between central zone and suburban zones is getting less, it is not worthwhile for some people and activities to pay higher rent for staying in the center due to its location advantage. Thus these people and industries start to move to suburban area, urban structure becomes decentralized, and subcenters appear. The less the commuting cost, the less the location matters. When the commuting cost equals zero, location has no influence. Population, employment and land rent density become uniform distributed and the density gradient is zero.

The idea of turning point of transport cost developed from our simulations is interesting. The value of the critical level of transport cost is arbitrary according to all given conditions in the beginning of the simulations. In short, this critical value is a function of the initial conditions: number of zones, initial values of parameters and variables. A different set of initial conditions will lead to a different value of critical level of transport cost. However, the interactions between the direction of the change of transport cost and urban structure mentioned above should be unchanged.

Given that the commuting cost below the critical level, our simulation also indicates that the size (i.e., final population) of the center zone and the gradient will be smaller if the initial commuting cost is lower. For example, there are two regions A and B, given all conditions and parameters the same except for the commuting cost. The commuting cost in region A is lower than in region B. After 30 units of time, according to the result of the model, region A will be more suburbanized than region B (i.e. the density gradient of region A is lower), and has a smaller size central zone. The predicted result of gradient corresponds to a sample of Japanese cities, where the transport cost is very high mainly due to congestion. The density gradients for Japanese cities are steeper.[2]

The estimated land rent gradients according to the data from simulations given different value of transport cost are shown in Table 2.[3]

Similar to the density gradient, the estimated slope has negative sign as in the reality, and the land rent gradient increases with commuting cost when the commuting cost is greater than the critical level. If the commuting cost is less than the critical level, the land rent gradient declines with the commuting cost. The decentralization of population, caused by a low commuting cost, is also reflected by a flatter land rent gradient.

Furthermore, it will be interesting to observe the effects of commuting cost on the dynamic pattern of both population density and the net agglomeration effect. The dynamic pattern of population density and the net agglomeration effect of three type of zones are shown in Fig.1,2 and 3 (corresponding to commuting cost is 1, 0.5 and 0.01). The population density and the net agglomeration effect of zone 1, 25, and 38 are presented in each figures. The three type of zones in the region are 1) zones on the border (presented by zone 1), 2) zones between the border and the center (presented by zone 38), and 3) the center zone or CBD (zone 25). In Fig.1, the population density of the center is apparently higher than those of the other two zones before

[2] See Mills and Hamilton, 1989

[3] Without any specific scenarios added into the simulation, the computer simulation results are likely to be symmetrical. The magnitude of the gradient can reflect the degree of centralization. The less the gradient, the less centralized the population. This gradient is a proper indicator to explain the population and land rent distribution as long as the urban structure is monocentric. Once the urban structure transforms to the polycentric pattern, the estimated density gradient is no longer a reasonable estimator, but a low gradient value still expresses that the urban structure is suburbanized.

Table 2. Estimated Density Gradient Given different Initial Unit Transport Cost

$$\ln(R_i) = \ln(R_0) + \lambda * d_i \quad (i = 1,...49 \text{ and } j=25)$$

Unit Transport Cost	$\ln(\hat{R}_0)$	$\hat{\lambda}$
	Estimated Intercept	$\lvert\hat{\lambda}\rvert$ is the Estimated Land Rent Gradient (fractional change per unit distance)
35	.0046	-.0690*
20	.0053	-.0760*
10	.0064	-.0853*
8	.0067	-.0879*
5	.0073	-.0922*
3	.0077	-.0959*
2	.0078	-.0994*
1.5	.0076	-.1004*
1	.0070	-.0930*
0.8	.0066	-.0860*
0.6	.0059	-.0762*
0.4	.0050	-.0634*
0.1	.0024	-.0279*

Notes:
Standard errors are in parentheses.
*Estimate is statistically significant at 0.05 level, 2-sided test.

time t=19. After time t=19, both the density and the net agglomeration effect of zone 38 exceed that of zone 25. The border zone has the lowest density and agglomeration effect due to its location disadvantage. The net agglomeration effect of the center, which has the highest location advantage, has steeper growing locus than the other zones, and first reaches its maximum net agglomeration level. Subcenters quite likely emerge as the net agglomeration effect of the center is declining and the net agglomeration effect of the other zone is growing or is at its maximum level.

When the commuting cost is reduced, the dynamic patterns of these three zones tend to be closed to each other under the same order, in which the density of zone 25 is the highest and the density of zone 38 is in the middle, in the first 17 time units. A lower commuting cost, indicating a diminishing location advantage, reduces the distinction between zones caused by different location. A lower commuting cost appears to accelerate the structure's evolutionary process according to the result of the simulation. As the commuting cost becomes very small and gets closer to zero, the location advantage disappears. Fig. 3 shows that three zones of different location have almost the same pattern of population density and net agglomeration effect. Each zone's agglomeration effect reaches its peak at the same time t=13, which is earlier than the other two figures. The level of commuting cost will affect the urban structure through agglomeration effect.

3.2 Experiment 2

In this experiment, we build a highway in the study region (as in Fig. 4), and investigate the growth of subcenter and its dynamic pattern. The employment density distributions at time t=8 and t=15 are presented in Figure 5 and 6. The net agglomeration effect distributions are presented in Figure 7 and 8. The profiles of employment density and net agglomeration effect along the highway at different time are presented in Figure 9 to 13. The employment density distribution is monocentric with center (4,4) in the beginning, and the center is growing and becomes dominant of the whole region (Fig. 5). At time t=15, subcenters (5,5) emerges and has higher employment density than the original center (4,4) (Fig. 6); meanwhile, the agglomeration effect of zone (5,5) is larger than that of CBD (4,4) at time t=15.

We observe the emerge of subcenter by the profile figures. From Fig. 9 to 13, zone (4,4) is the only one center in the region because of its highest net agglomeration effect, which is resulted from the locational advantage. Therefore, employment density distributions are monocentric between time t=8 and t=14. Center (4,4) grows and dominates the region until its negative agglomeration effect is increasing and over the positive agglomeration effect. Due to the large negative agglomeration effect of center (4,4), another center emerges and grows with the growth of its net agglomeration effect (Fig. 12 and 13). It is 2 "twin centers", similar to well-known cases of "twin cities" such as Minneapolis-St.Paul except that they both started at small and grew. As the net agglomeration effect of center (4,4) grows slower and starts declining, subcenter (5,5) has higher net agglomeration effects than the original center (4,4). At this time, subcenter (5,5) grows to be the employment center of the region. The dynamic pattern of employment density of center (4,4) and subcenter (5,5) for 20 time periods is presented in Figure 14. Center (4,4) has higher employment density than subcenter (5,5) until time t=15, where its net agglomeration effect starts decreasing and is less than that of subcenter (5,5).

4. Conclusions

The simulation shows that the lower the commuting cost, the flatter the density and land rent gradients, and the smaller the size of the CBD. In other words, a reduction in commuting cost will result in a more suburbanized urban area. The land rent distribution is dispersed along with the decentralized population distribution. Moreover, if commuting cost is zero, the model will predict that population, employment and land rent are uniformly distributed.[4]

During the evolution process, some centers emerge outside the CBD. This is due to a reduction in commuting cost and a decline in the central city's agglomeration effect. As the size of central city is getting bigger, the negative agglomeration effect becomes larger relatively to the positive agglomeration effect. Once the negative effect is stronger than the positive effect, the net agglomeration effect is declining. Subcenters are inclined to emerge under the situations that central city is declining and commute cost is reduced.

Population and activities tend to distribute along transportation systems. In reality, land which is more accessible to highways will be more expensive than land located far from transportation systems. It is clear that transportation policy decisions will influence the population distribution of the whole urban area.

This paper presents that the level of commuting cost has large influences on the urban structure. It may affect the population and employment distributions directly,

[4] Mills and Hamilton (1989) Ch. 7 and Ch. 15.

or indirectly through the effects on net agglomeration economies. In addition, we observe the formation of subcenters dynamically and find that the change of net agglomeration economies distributions are highly related to the growth of subcenters.

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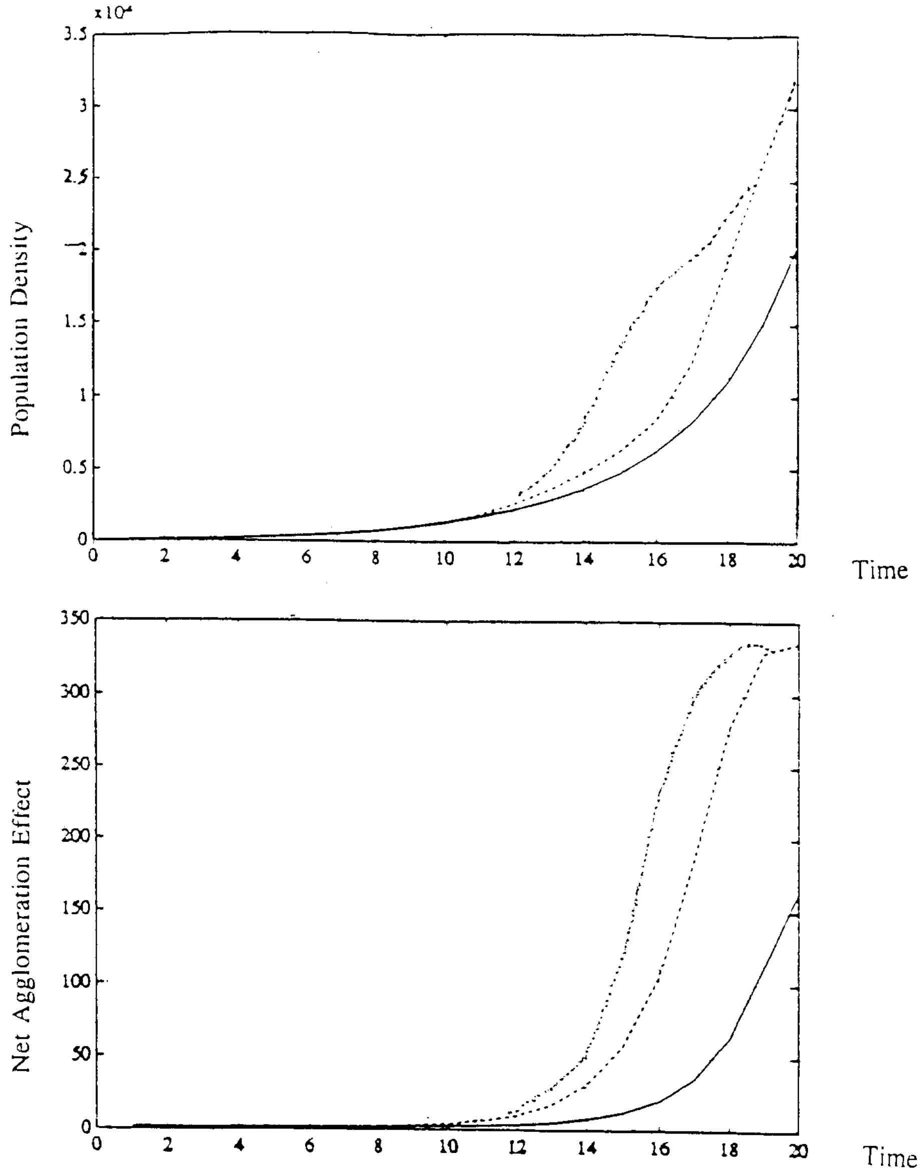


.... center zone (zone 25)
- - - - - - - - - - - zone 38 (between center and border)
———————————— border zone (zone 1)

Fig. 1. The Dynamic Population Density and Net Agglomeration Effect. (commuting cost = 1)

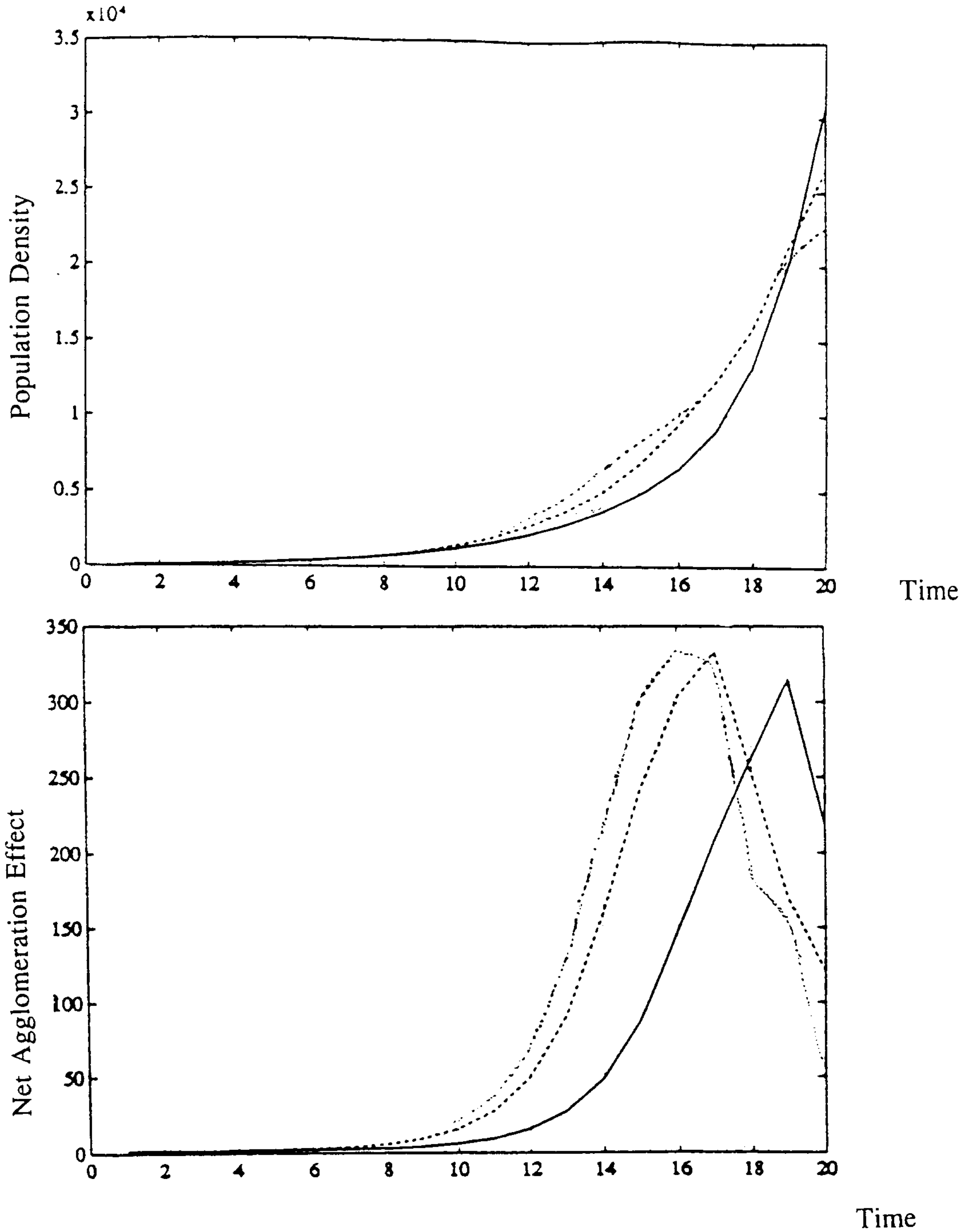


Fig. 2. The Dynamic Population Density and Net Agglomeration Effect. (commuting cost = .5)

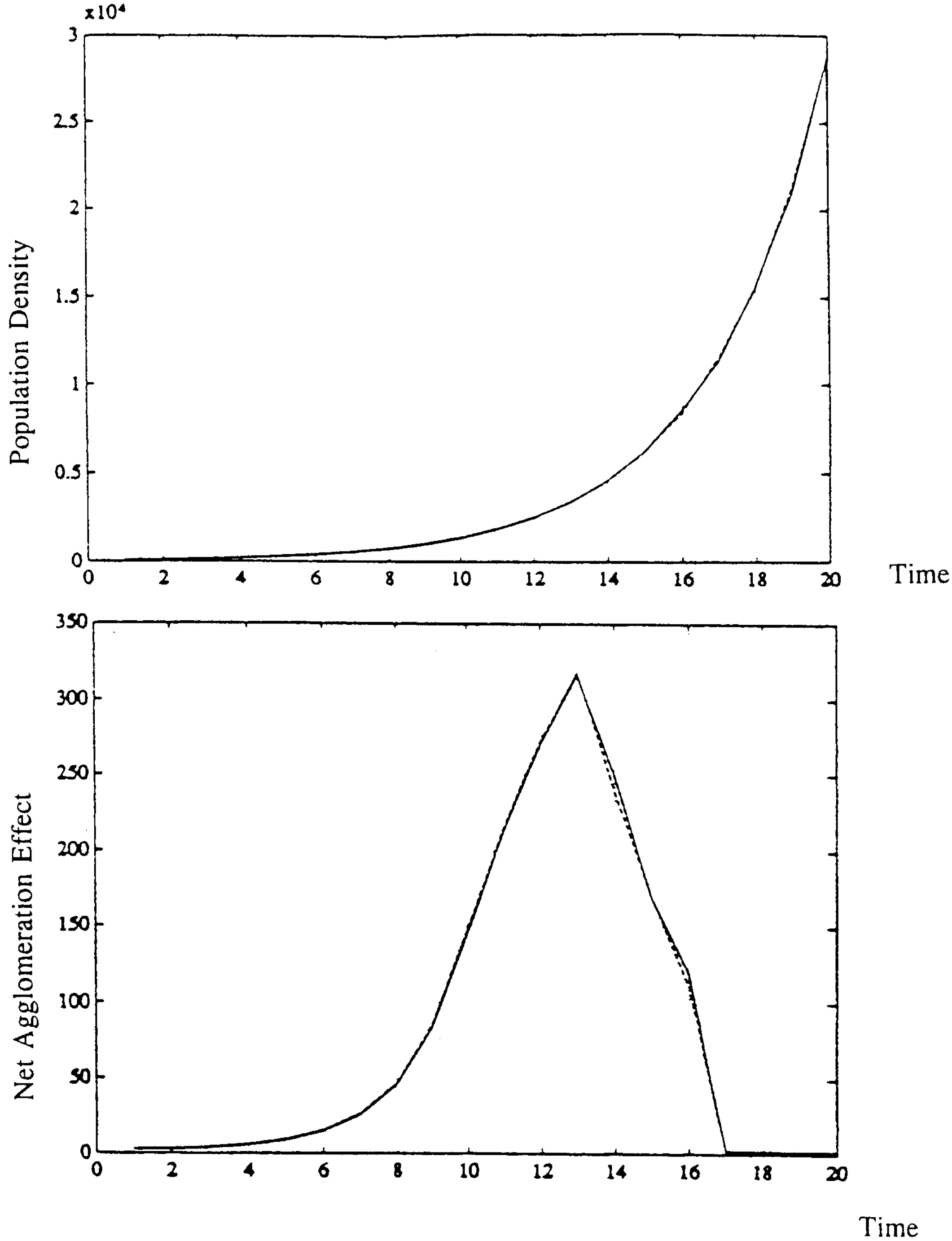


Fig. 3. The Dynamic Population Density and Net Agglomeration Effect. (commuting cost = .01)

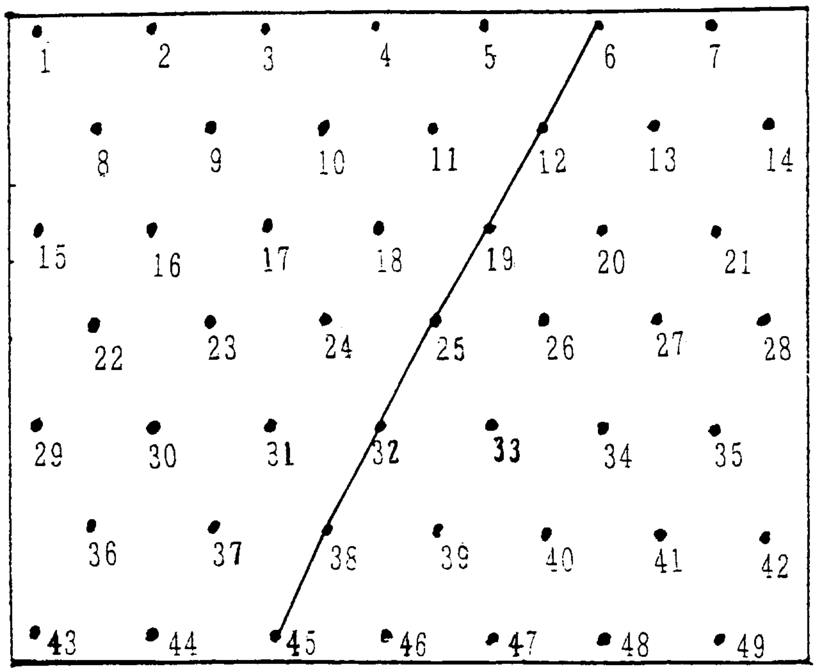


Fig. 4. Simulation Region and The Location of Highway in Rectangular Grids with Zone Numbers.

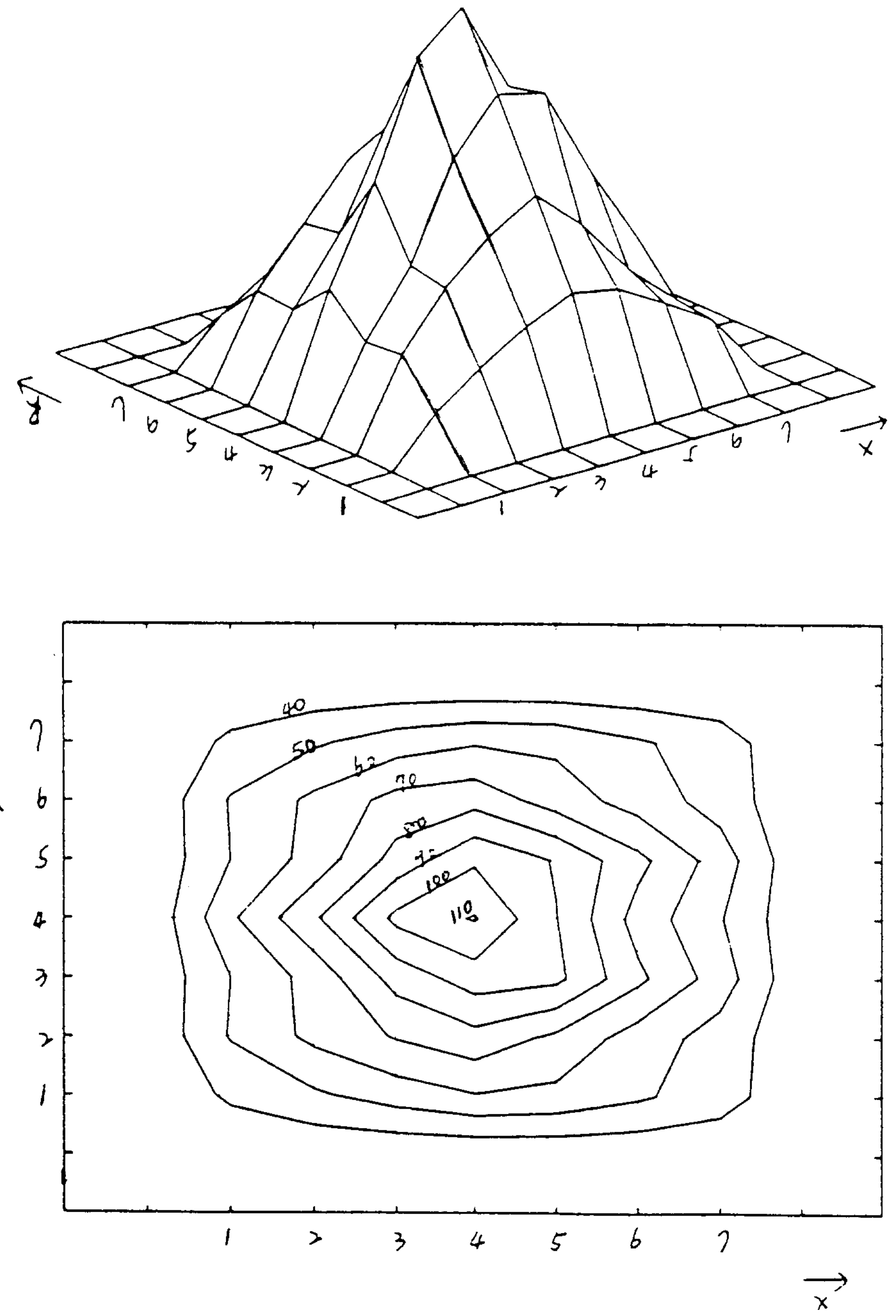


Fig. 5. The Employment Density at time t = 8

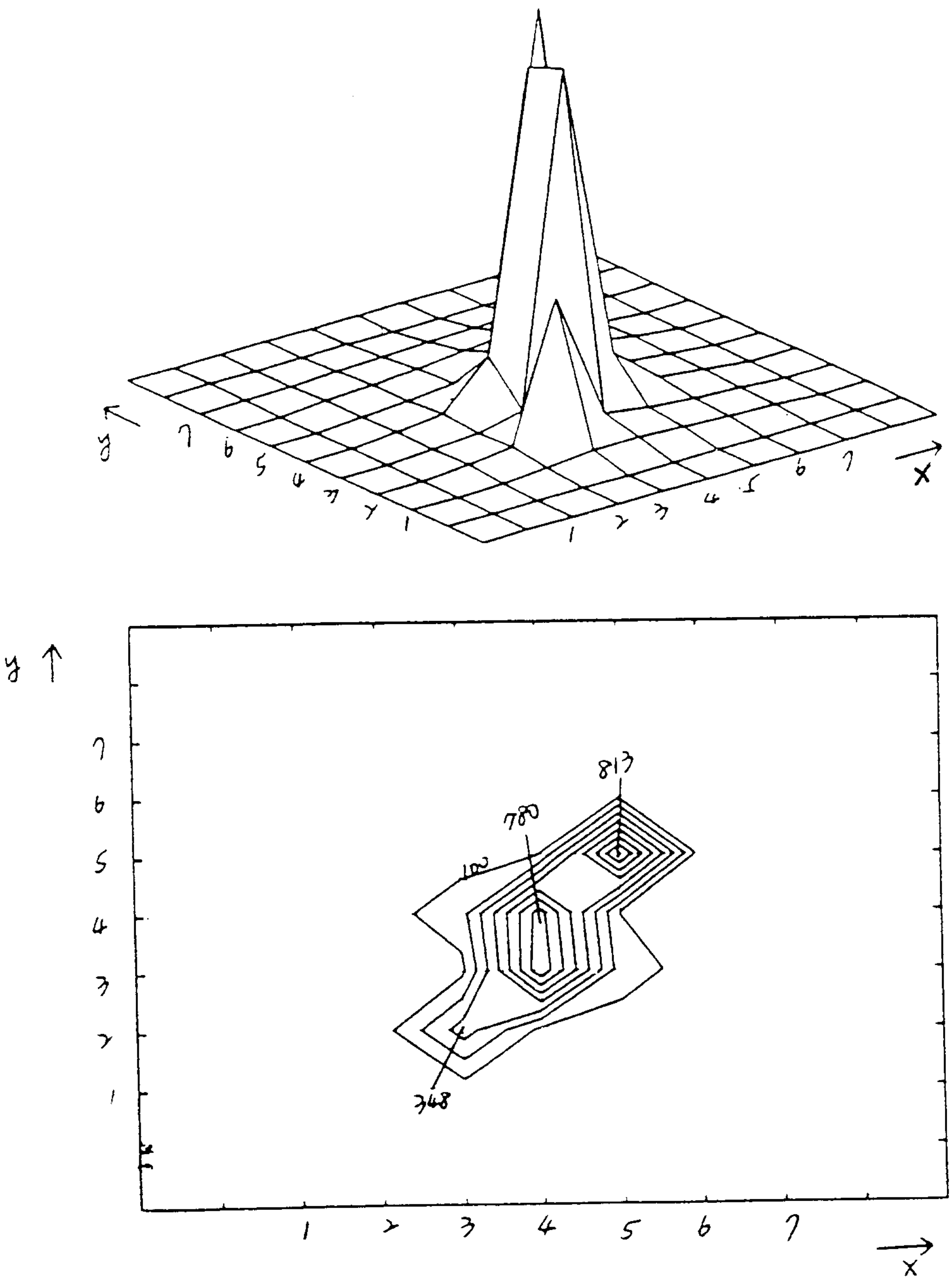


Fig. 6. The Employment Density at time 5 = 15.

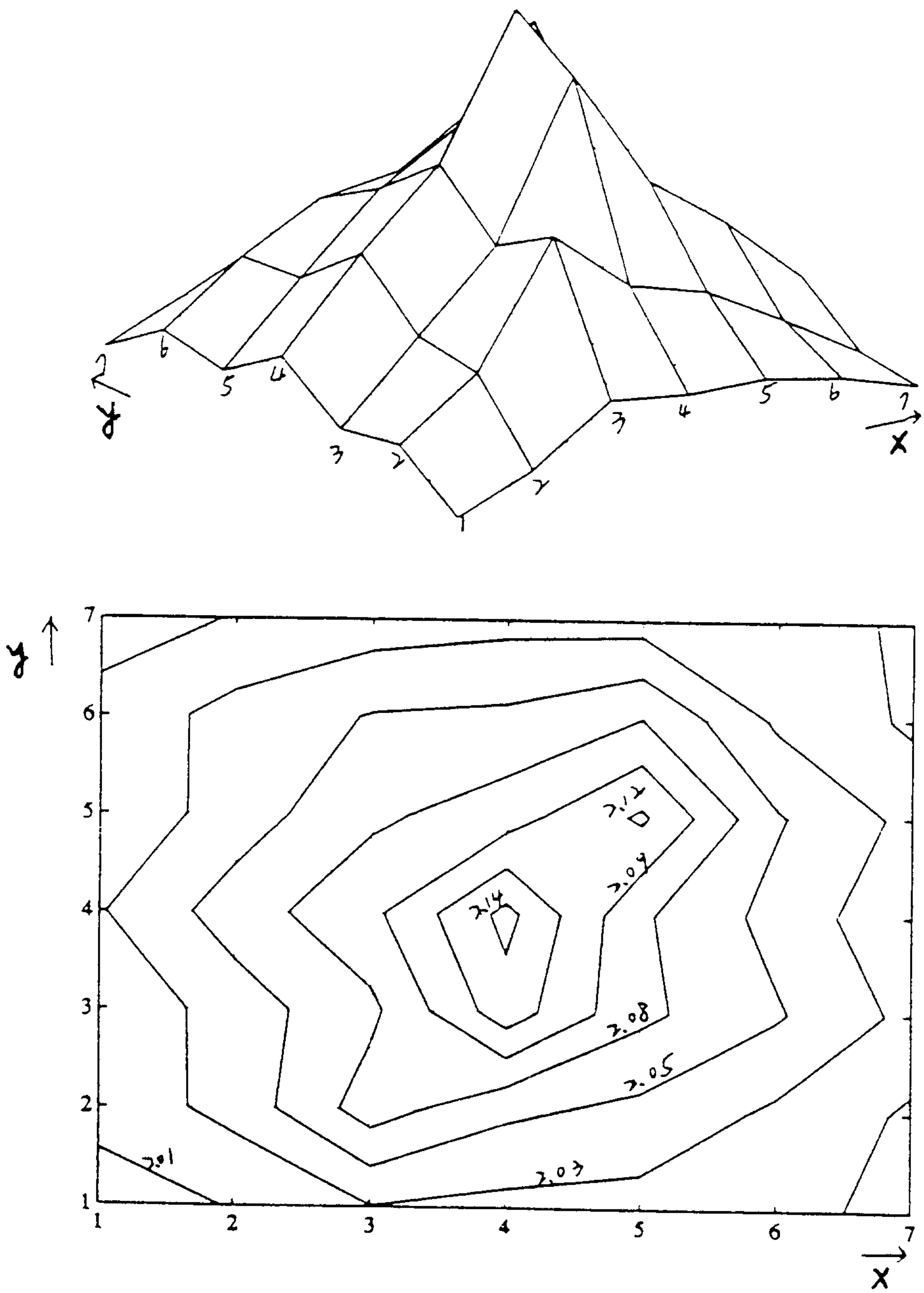
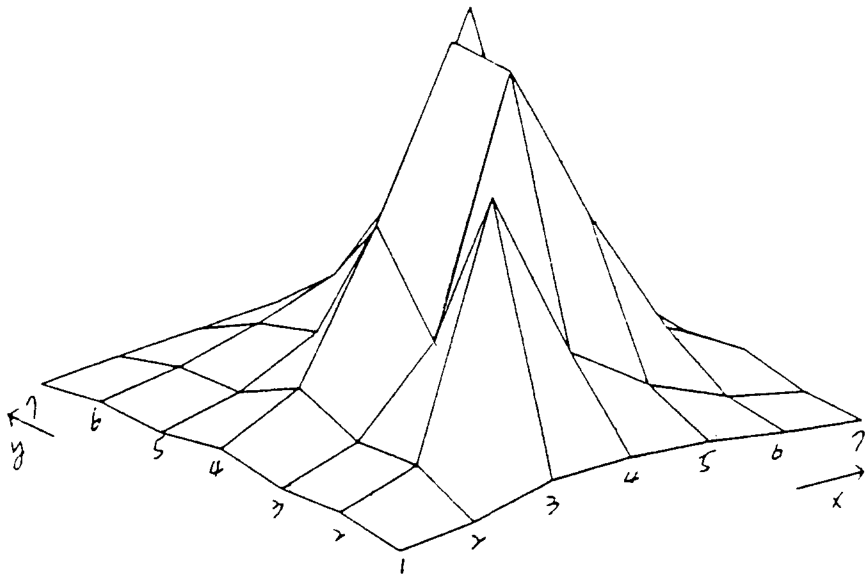


Fig. 7. The Net Agglomeration Effect at time t = 8.



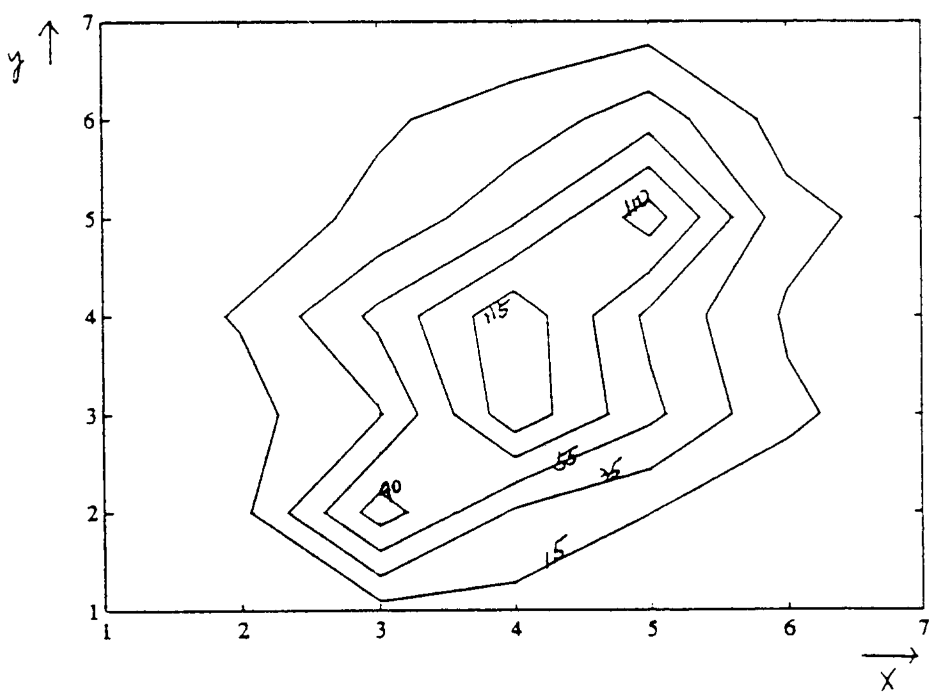
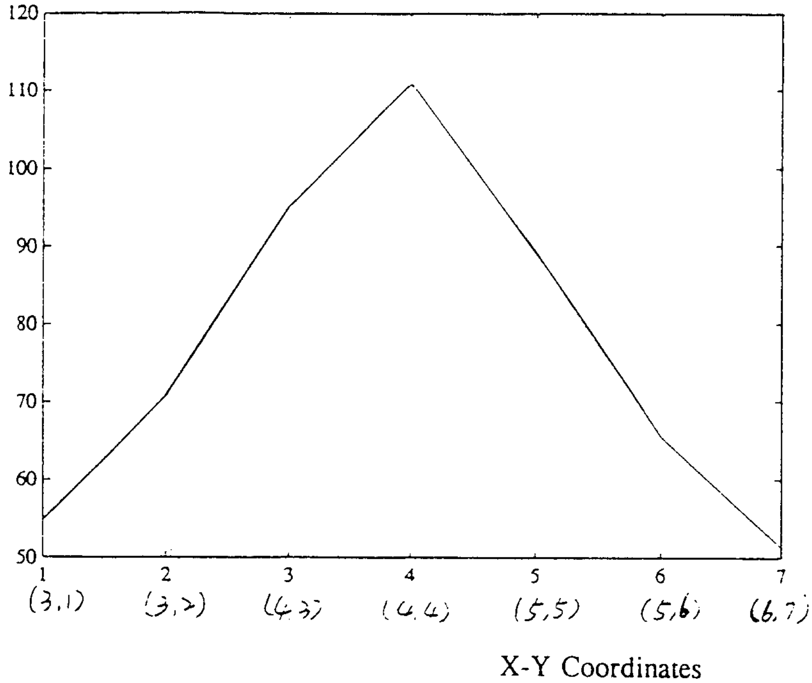


Fig. 8. The Net Agglomeration Effect at time t = 15.



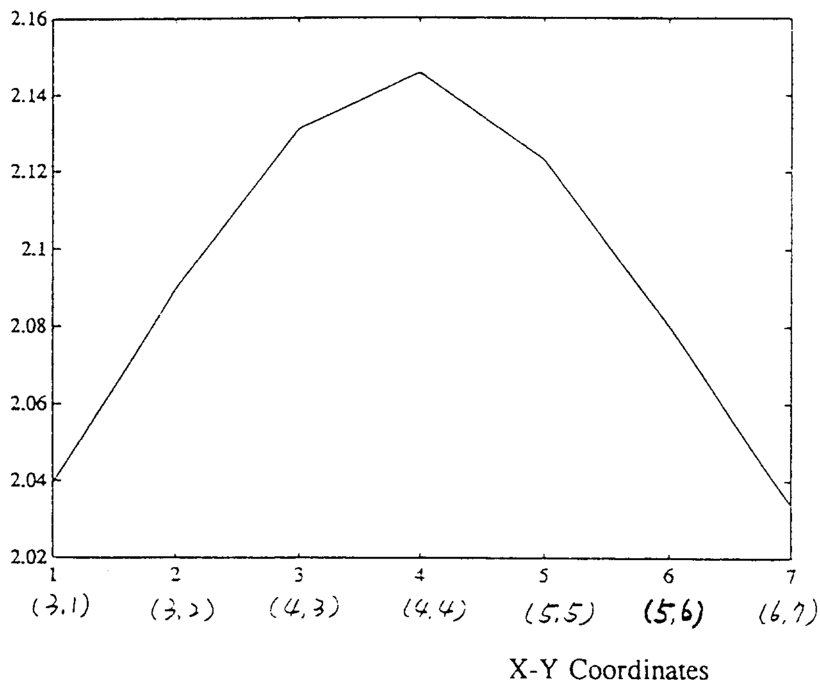
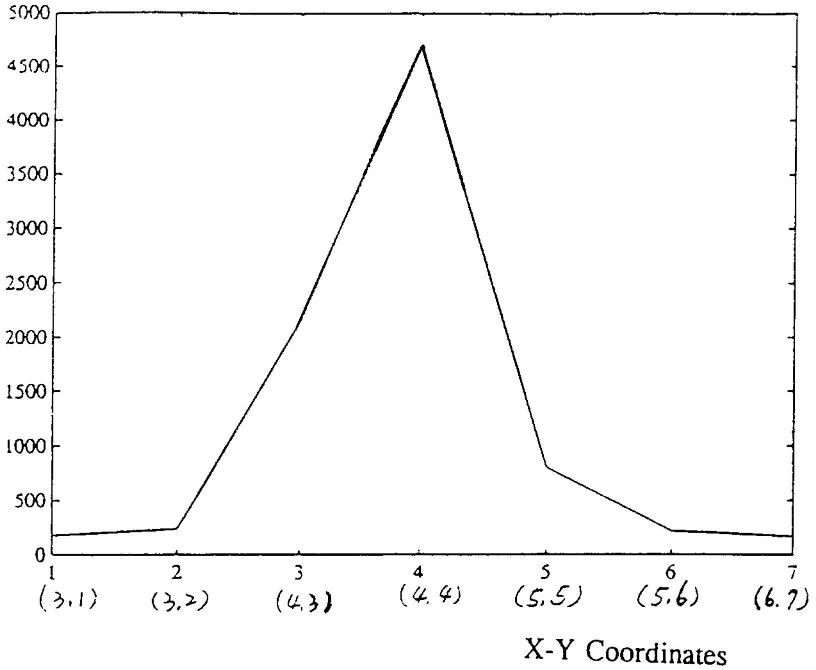


Fig. 9a(up). The Profile of Employment distribution at time t = 8.
9b(down). The Profile of Net Agglomeration effect at time t = 8.



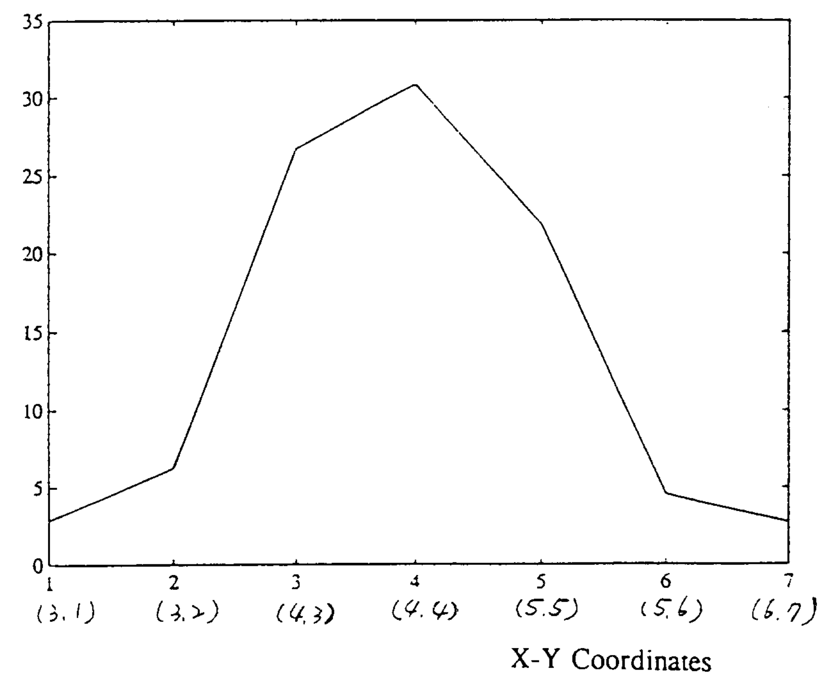


Fig. 10a(up). The Profile of Employment distribution at time t = 12.
10b(down). The Profile of Net Agglomeration effect at time t = 12.

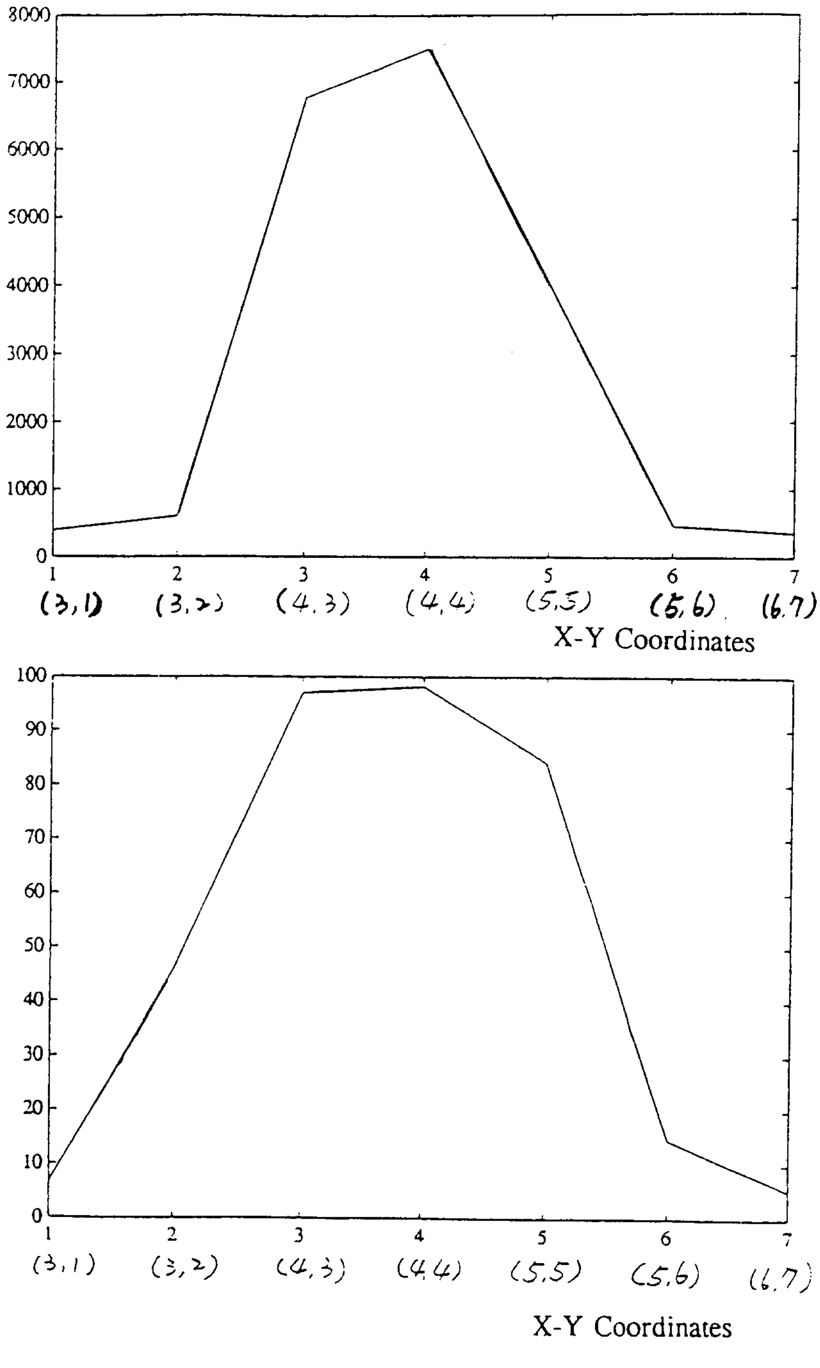
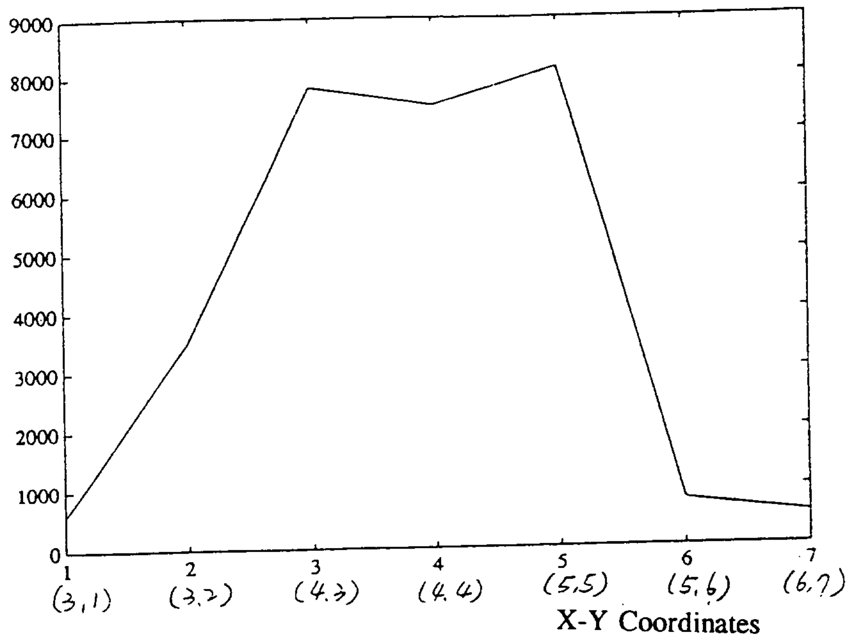


Fig. 11a(up). The Profile of Employment distribution at time t = 14.
11b(down). The Profile of Net Agglomeration effect at time t = 14.



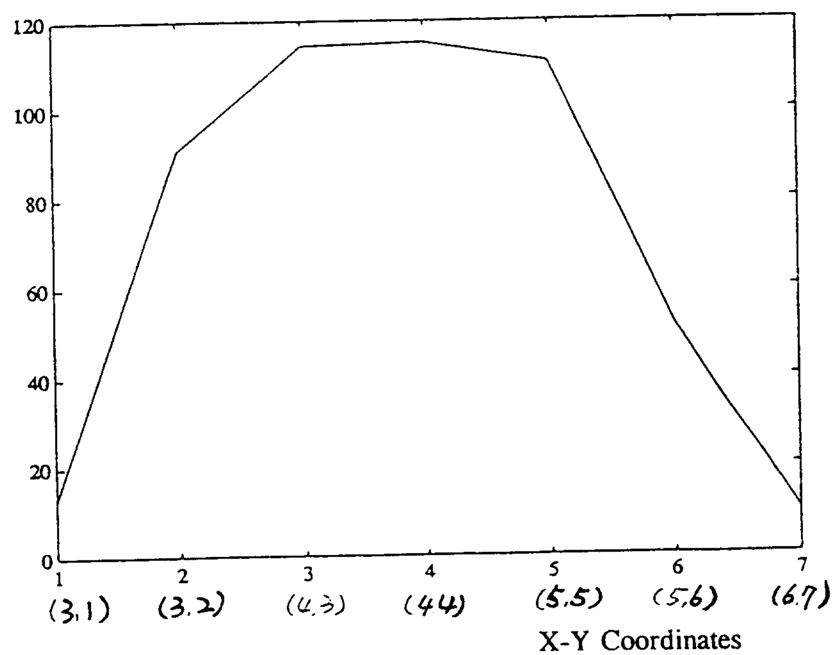


Fig. 12a(up). The Profile of Employment distribution at time t = 15.
12b(down). The Profile of Net Agglomeration effect at time t = 15.

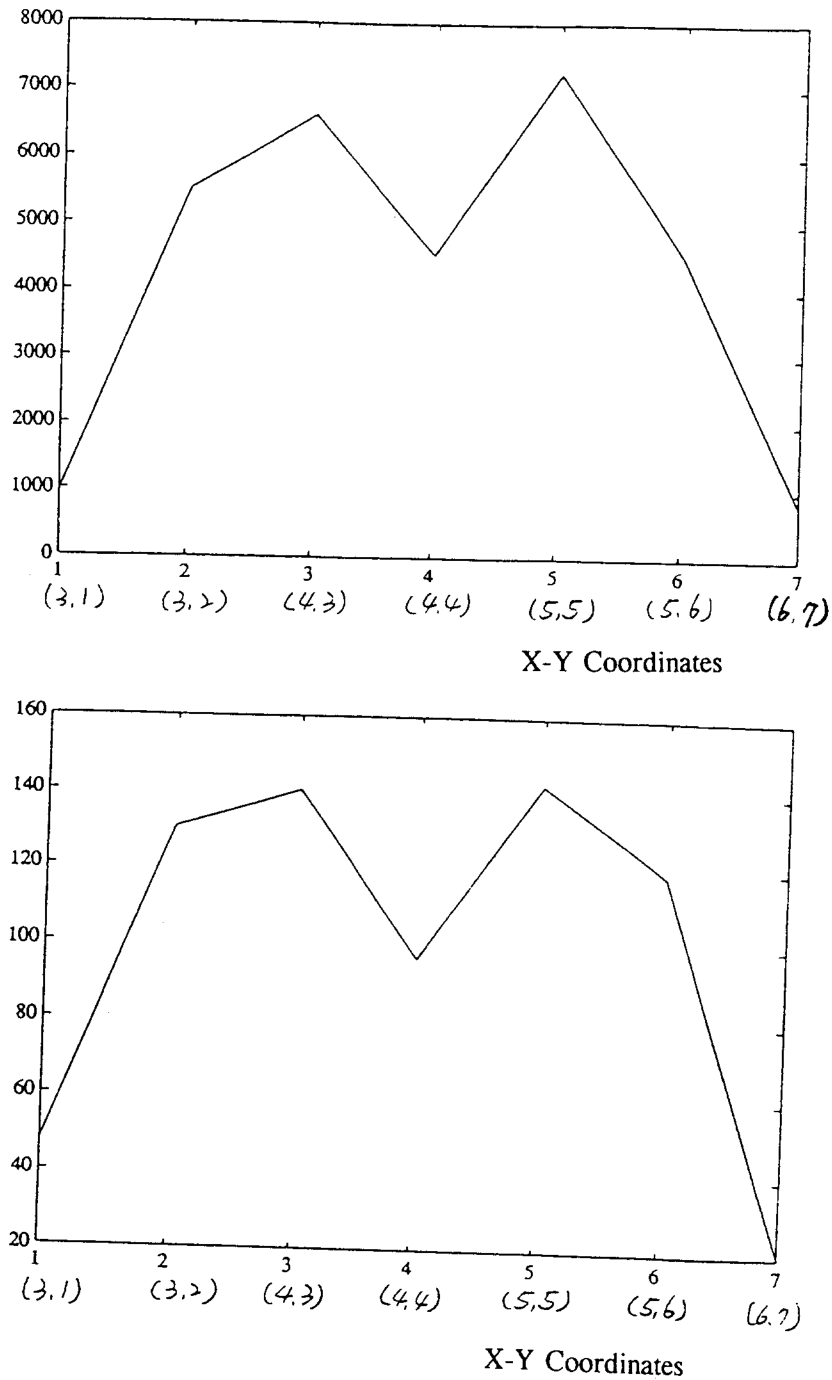


Fig. 13a(up). The Profile of Employment distribution at time t = 16.
13b(down). The Profile of Net Agglomeration effect at time t = 16.

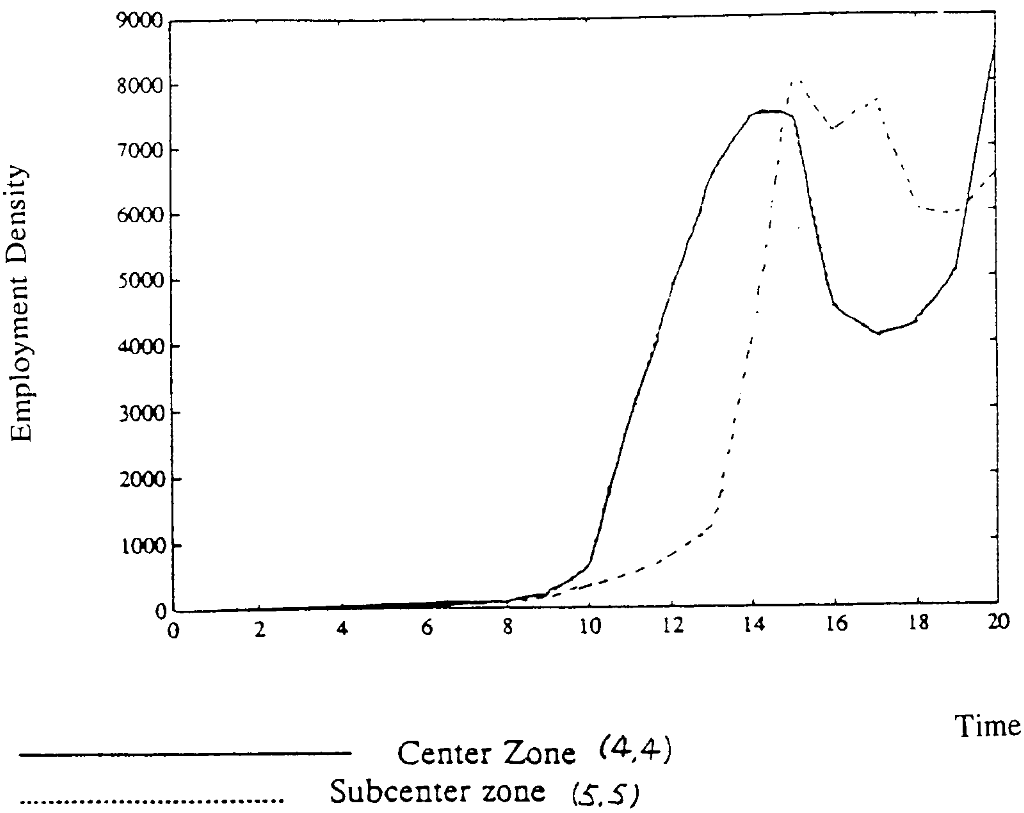


Fig. 14. The Dynamic Employment Density