# A SIMULATION MODEL FOR DEVELOPING SERVICE CENTERS IN A RURAL SETTLEMENT NETWORK

Ryszard Domanski* and
Andrzej P. Wierzbicki

May 1981
WP-81-58

*Rector, Academy of Economics
Poznan, Poland.



INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS
A-2361 Laxenburg, Austria

# PREFACE

The work of the Regional Development Task at the International Institute for Applied Systems Analysis (IIASA) focuses on problems of medium- and long-term regional development. In this context the restructuring of settlement networks forms an important part of the development of regions. A critical aspect of this restructuring is the development of service centers.

This paper presents a dynamic simulation model for developing service centers in a rural settlement network, together with the results obtained from running the model. These results are interpreted in terms of human settlement theories.

The paper has been prepared in collaboration with the System and Decision Sciences Area at IIASA.

# A SIMULATION MODEL FOR DEVELOPING SERVICE CENTERS IN A RURAL SETTLEMENT NETWORK

Ryszard Domanski and Andrzej P. Wierzbicki

## INTRODUCTION

Rural settlement patterns in European countries as well as in other parts of the world are characterized by great dispersion. Such patterns indicate that many small settlement units such as villages, hamlets,and single farms exist. The majority of these small units are poorly supplied with both technical and social services, and their low economic efficiency, related to the small scale of the facilities needed, is an obstacle to improving service provision.

In turn, the poor supply of services retards the development of agricultural production and hinders the raising of living standards for the rural population. It is, therefore, a subject of deep concern to rural planners and policy makers.

Settlement patterns in rural areas are shaped by various forces. Some (e.g. intrafarm location factors) encourage dispersion within the pattern, others (e.g. infrastructure, market) stimulate its concentration. In recent years, the concentrating forces have generally been stronger.

Their influence has led to a restructuring of settlement networks. Some villages are continuously increasing, undergoing industrialization and urbanization, as well as enjoying a growing range and level of services. Others suffer from continuous depopulation, decreasing job opportunities, and a low level of services. Over time the latter type of village becomes increasingly unsuited to modern life.

Some of the prosperous villages become key villages and gain new functions. They take on the role of service centers with facilities serving not only their own population but also the population of surrounding areas. Agriculture is usually more intensive in such villages; thus, the development of the food-processing industry is stimulated.

This natural process is directly encouraged in many countries through the socio-economic policies pursued. In such cases, the development of villages is considered as a means of improving the satisfaction of human needs and of increasing the efficiency of investments and economic activities.

In order to be effective, policies for restructuring settlement networks in rural areas should be based on an understanding of the underlying socio-economic processes. Models of these processes can be used to produce a set of development projections under various assumptions, regarding resources, and constraints. Thus, they enable policy makers to trace, evaluate, and make reasonable choices between various possible paths of growth.

## THE SIMULATION MODEL

In this section a model for developing service centers in a rural settlement network is presented. Through the development of service centers, a restructuring of the network occurs. Restructuring is used in the sense of changes made to the locational and hierarchical pattern of the settlement network that occur as a result of the growth of some elements of the network, the shrinking of others, and the shifting of elements between the hierarchical levels. This also implies that there will be changes in the pattern of mutual interaction between elements.

In general, the restructuring process results in the emergence of key villages; the decline of small towns, villages, and hamlets; and the growth of regional urban centers. Since key villages are the settlement units that, rural planners hope, will help to rationalize the whole rural settlement pattern, most attention is given to the emergence of this type of village.

Structural changes, because of their complexity, are extremely difficult to model. The difficulties may be overcome by the application of the relevant theory and methodology. Among the theories that may be applied, Prigogine's theory of self-organization in nonequilibrium systems (Nicolis and Prigogine 1977) seems to be particularly promising. It has been already successfully applied in economic geography by Allen and Sanglier (1979), who have elaborated a dynamic model of growth in urban systems.

In this paper the conceptual framework of Allen and Sanglier is used. However the model developed within this framework differs from that of Allen and Sanglier. The model framework specified in Domanski (1980) will be briefly referred to, since a new version of the model described there is presented in this paper.

The initial state of the settlement network changes as a result of two factors: the introduction of a new economic activity in a settlement unit, and the interaction between the settlement units within the network.

It is assumed that the evolution of the settlement network results from the mutual interaction of the spatial distribution of economic activities and the population. The distribution of economic activities can be reflected by the distribution of employment. Thus, in the model, employment may be substituted for economic activities and it may be related to population. An increase in employment is followed by an increase in population. This, in turn, creates new resources of labor, new markets, and new employment opportunities. The impact of employment on the population opens up a cycle of mutual interactions.

Mutual interaction creates conditions in which self-organization of the system can occur. It may start with small changes in employment (population) occurring during successive periods of time. These changes are thereafter amplified by the interaction of the elements of the system. Through the cumulative causation and amplification mechanism, interaction eventually leads to a qualitative change in the macroscopic structure of the system.

The rural economy is disaggregated into three sectors: agriculture, industry, and services. Agriculture is the basic activity of a rural region included in each settlement but in some settlements the food-processing industry is also included. Key villages are distinguished from other villages and hamlets because they include service activities. Services can have a dual function. They can be provided for agricultural production as well as for the rural populations.

The model of the development of service provision in a rural region is a dynamic simulation model. There is a network of settlements, with locations denoted by x (or $\bar{x}$ or y) and the distance $d_{xy}$ between any two settlements x,y is given (Figure 1). Population, employment in intensive agriculture and/or industry, as well as employment in services develop over time. Time is counted by discrete periods t = 0,1,...,30,...,50. At each time t, every settlement is characterized by the following variables:*

(*) $P_{x,t}$ = population at location x and time t;

(*) $E^{v}_{x,t}$ = employment in occupation v at location x and time t ((*) v = 1 denotes industry, v = 2 denotes intensive agriculture);

(*) $E^{u}_{x,t}$ = employment in service u at location x and time t ((*) u = 1,...,5; i.e five services are considered in the model).

$$E^{0}_{x,t} = \frac{1}{k} P_{x,t} - \sum_{y=1}^{2} E^{v}_{x,t} - \sum_{u=1}^{5} E^{u}_{x,t} \qquad (1)$$

* (*) is used in this paper to denote a new variable or parameter that is introduced and defined.

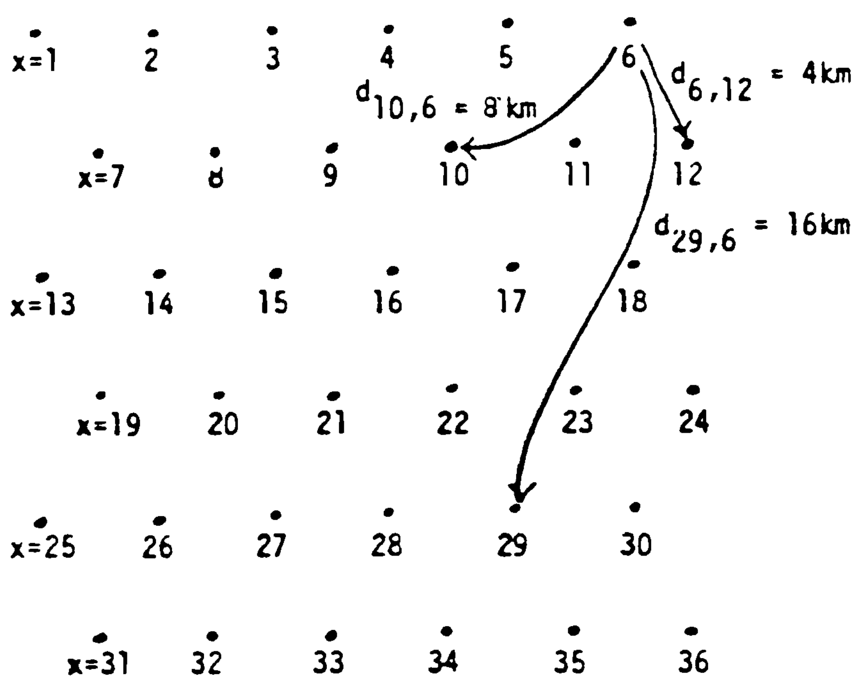


Figure 1. The network of settlements.

denotes the employment potential at location x and time t (interpreted as the number of people employed in traditional agriculture). The model parameter (*) k is the number of family dependents per employee and is assumed to be constant for the entire network (k = 3 has been used in the simulations). Moreover:

$$R_{x,t} = \sum_{u=1}^{5} E^{u}_{x,t} \qquad (2)$$

denotes the total employment in services at location x and time t. The entire network is characterized by total variables as given in equations (3)-(7).

$$P_{T,t} = \sum_{x \in X} P_{x,t} \qquad (3)$$

is the total population of the network at time t, while X denotes the set of all settlements.

$$E^{v}_{T,t} = \sum_{x \in X} E^{v}_{x,t} \tag{4}$$

is the total employment in occupation v at time t.

$$E^{u}_{T,t} = \sum_{x \in X} E^{u}_{x,t} \tag{5}$$

is the total employment in services u at time t.

$$R_{T,t} = \sum_{x \in X} R_{x,t} \tag{6}$$

is the total employment in services at time t. Finally:

$$E^{0}_{T,t} = \sum_{x \in X} E^{0}_{x,t} \tag{7}$$

is the total potential for employment at time t.

The dynamic nature of the model results from the growth equations:

$$P_{x,t+1} = (1 + r)P_{x,t} + M_{x,t} \quad , \qquad P_{x,0} \text{ is given,} \tag{8}$$

where

(*) $r$ = the population growth rate, which is a model parameter assumed to be constant in the network ($r = 0.01$ has been used in the simulations);

(*) $M_{x,t}$ = the total immigration to location x at time t, determined by the *migration mechanism*, explained below;

(*) $P_{x,0}$ = the initial population, which is a parameter of the model (set independently for each x, but $P_{x,0} = 500$ for all x has been used in the simulations).

$$E^{v}_{x,t+1} = E^{v}_{x,t} + \Delta^{v}_{x,t} \ , \qquad E^{v}_{x,0} \text{ is given,} \tag{9}$$

where

(*) $\Delta^{v}_{x,t}$ = the increase of employment in occupation v at location x and time t, determined by the *occupational-employment mechanism* explained below;

(*) $E^{v}_{x,0}$ = initial employment in occupation v; this is a parameter of the model (set independently for each x, but $E^{v}_{x,0} = 0$ for all x has been used in the simulations).

$$E^{u}_{x,t+1} = E^{u}_{x,t} + \Delta^{u}_{x,t} \ , \qquad E^{u}_{x,t_{ou}} \text{ is generated,} \tag{10}$$

where

(*) $\Delta^{u}_{x,t}$ = the increase of employment in service u at location x and time t, determined by the *service-employment mechanism*, which is one of the main features of the model explained below;

(*) $E^{u}_{x,t_{ou}}$ = the initial employment in service u, generated at time $t_{ou}$ when a service is introduced in the network by the *service-generation mechanism*, which is another main feature of the model explained below.

The *migration mechanism* assumed in the model is relatively simple. No immigration from other regions is considered; hence, the network is closed. Full mobility within the network is assumed and immigration to a location x responds immediately to employment opportunities at this location:

$$M_{x,t} = k\left(\sum_{u=1}^{5} \Delta^{u}_{x,t} + \sum_{v=1}^{2} \Delta^{v}_{x,t} - \upsilon E^{0}_{x,t}\right) . \qquad (11)$$

Thus, immigration results from new employees and their dependents (employees multiplied by k) minus potential employees and dependents from the pool $E^{0}_{x,t}$ either staying in the same location or emigrating to find employment in other locations; the coefficient $\upsilon$ is chosen to satisfy the closeness condition:

$$\sum_{x \in X} M_{x,t} = 0, \qquad (12)$$

which results in

$$\upsilon = \frac{\sum_{x \in X}\left(\sum_{u=1}^{5} \Delta^{u}_{x,t} + \sum_{v=1}^{2} \Delta^{v}_{x,t}\right)}{E^{0}_{T,t}} . \qquad (13)$$

Clearly, the migration mechanism could be made more realistic by assuming first commuting of employees to work and then delayed migration. However, these aspects have not been considered crucial to the model and can be improved in later versions.

The *occupational-employment mechanism* is also extremely simple, since the purpose of the model is to represent the dynamic changes resulting from the development of services, rather than from the development of industry and agriculture. It is assumed that the opportunity of employment (in services, industry, or intensive agriculture) attracts people from the employment pool $E^{0}_{T,t}$ of the entire network:

$$\Delta^{v}_{x,t} = \delta^{v}_{x} E^{0}_{T,t} , \qquad (14)$$

where (*) $\delta^{v}_{x}$ are the parameters of the model, constant in time but specified independently for each occupation and each location. By setting $\delta^{v}_{x} = 0$ or $\delta^{v}_{x} \neq 0$, we can define at which locations there is a development of intensive agriculture and/or industry. For example, three variants of the distribution of $\delta_x^v$ have been assumed in the simulations:

Variant I:

Industry : $\delta_x^1 = \begin{cases} 0.005, & x = 2, 12, 15, 23, 26, 34 \\ 0, & \text{otherwise} \end{cases}$

Agriculture : $\delta_x^2 = \begin{cases} 0.002, & x = 9, 10, 12, 15, 16, 21, 22, 23, 26, 27, 28 \\ 0, & \text{otherwise} \end{cases}$

Variant II:

Industry : $\delta_x^1 = \begin{cases} 0.0005, & x = 2, 12, 15, 23, 26, 34 \\ 0, & \text{otherwise} \end{cases}$

Agriculture : $\delta_x^2 = \begin{cases} 0.0002, & x = 9, 10, 12, 15, 16, 21, 22, 23, 25, 27, 28 \\ 0, & \text{otherwise} \end{cases}$

Variant III:

Industry : $\delta_x^1 = \begin{cases} 0.005, & x = 2, 11, 14, 23, 26, 35 \\ 0, & \text{otherwise} \end{cases}$

Agriculture : $\delta_x^2 = \begin{cases} 0, & x = 2, 11, 14, 23, 26, 35 \\ 0.002, & \text{otherwise} \end{cases}$

Clearly, many other more realistic occupational-employment mechanisms could be assumed, but such assumptions have not been considered crucial to the model.

The essential parts of the model are the *service-generation* and *service-employment* mechanisms. It has been assumed that services are introduced in the network at starting times $t_{uo}$. These times are parameters of the model, which have been specified in the simulations as follows:

$$t_{uo} = 0,\ 5,\ 10,\ 15,\ 20 \quad , \quad \text{for } u = 1, 2, 3, 4, 5$$
$$(t_{uo} = 5(u-1)) \quad . \qquad (15)$$

It has also been assumed that $E_{x,t}^u = 0$ for $t < t_{uo}$, for all locations x. At time $t_{uo}$, employment $E_{x,t_{uo}}^u$ is randomly generated to be either $E^{uo}$ or 0, where (*) $E^{uo}$ represents the minimal employment in service u above which the introduction of the service is efficient. It is a parameter of the model, independent of location and time, but dependent on the service type. In the simulations it has been assumed that:

$$E^{1o} = 5, E^{2o} = 10, E^{3o} = 15, E^{4o} = 20, E^{5o} = 25 \quad (E^{uo} = 5u) \quad . \tag{16}$$

The random rule of generating the service at time $t_{uo}$ is defined by the probabilities:

$$\begin{aligned} p(E^{u}_{x,t_{uo}} = E^{uo}) &= p_0(P_{x,t}, R_{x,t}, \gamma) \quad , \\ p(E^{u}_{x,t_{uo}} = 0) &= 1 - p_0(P_{x,t}, R_{x,t}, \gamma) \quad , \end{aligned} \tag{17}$$

where

$$p_0(P_{x,t}, R_{x,t}, \gamma) = \psi_1 \frac{(P_{x,t} + \gamma R_{x,t})N}{\sum_{\bar{x} \in X} (P_{\bar{x},t} + \gamma R_{\bar{x},t})} \quad , \tag{18}$$

(*) $\psi_1$ = an unmodified probability of service generation; this is a parameter of the model ($\psi_1 = 0.1667$, for all x,u, has been used in the simulations);

(*) N = the number of settlements in the network;

(*) $\gamma$ = a service-agglomeration parameter (the existence of already introduced services, $R_{x,t} > 0$, might strongly influence the probability of introducing a new service; $\gamma = 100$ or $\gamma = 0$ has been used in the simulations).

Thus, the probability of introducing a new service has an average level of $\psi_1$ but is modified and increased depending on the relative population of the settlement and, more strongly so, depending on the relative employment in already introduced services.

The random rule for generating a service is also repeated at time $t > t_{uo}$, but in a modified sense:

$$p^c(E^u_{x,t} \geqslant E^{uo}) = p_1(P_{x,t}, R_{x,t}, \gamma) \quad ,$$
$$p^c(E^u_{x,t} = 0) = 1 - p_1(P_{x,t}, R_{x,t}, \gamma) \quad , \tag{19}$$

where

$$p_1(P_{x,t}, R_{x,t}, \gamma) = \min\left(1, \psi_2 \frac{(P_{x,t} + \gamma R_{x,t})N}{\sum\limits_{\bar{x} \in X} (P_{\bar{x},t} + \gamma R_{\bar{x},t})}\right) . \tag{20}$$

Here, (*) $\psi_2$ is another unmodified probability of service generation, a constant parameter of the model. However, $\psi_2 \neq \psi_1$ can be assumed and, operationally, $\psi_2 >> 1$ can also be used (with the interpretation that $p^c\ (E^u_{x,t} \geqslant E^{uo}) = 1$, for all x, if $\psi_2 >> 1$; two variants $\psi_2 = 0.1667$ and $\psi_2 = 1000$ have been used in the simulations).

The probability $p^c\ (E^u_{x,t} \geqslant E^{uo})$ does not mean, however, that service u will be introduced at location x and time t at level $E^{uo}$, after location x has been randomly selected. It implies merely that the introduction of service u at this randomly selected location x will *be considered* in accordance with the service-employment mechanism and, if the demand for this service at this location is estimated as satisfactory, the service will finally be introduced. The random selection of locations in which the introduction of services is considered applies only to such x that $E^u_{x,t-1} = 0$. If $E^u_{x,t-1} > 0$, the service-employment mechanism based on an estimation of the demand is always applied.

This particular way of service generation has a reasonable real-life interpretation. The moment that the need for a new service is perceived, a small number of service units is randomly introduced without really estimating the demand, but based only on the belief that there is sufficient demand. In the next periods, however, existing service units adjust their size to the demand, and new service units are initiated only after existing demand has been estimated. The demand estimation and the consideration of whether to introduce new service units can be made either at all settlements (high value of $\psi_2$) or only at randomly selected settlements at any instant of time. Thus, a random distribution and delay in service generation might occur. However, the distribution and delay are influenced by the population size and might depend heavily on the existence of other services.

The service-employment mechanism is based on demand estimation and an adaptive-employment mechanism. Although demand estimation could be treated jointly for the cases when $E^u_{x,t} = 0$ and when $E^u_{x,t} > 0$, these cases have been separated here for the sake of clarity of presentation. If $t > t_{uo}$ and $E^u_{x,t} > 0$, we estimate first:

$$A^u_{xy,t} = \begin{cases} \dfrac{E^u_{x,t} + \sum\limits_{\bar{u} \neq u} \lambda_{\bar{u}u} E^{\bar{u}}_{x,t}}{d^{\alpha}_{xy}} , & \text{if } E^u_{x,t} > 0 \text{ and } d_{xy} \leqslant D_0 , \\ 0 , & \text{if either } d_{xy} > D_0 \text{ or } E^u_{x,t} = 0 , \end{cases} \tag{21}$$

where

(*) $A^u_{xy,t}$ = the attractiveness of service u at location x for possible customers from location y;

(*) $\lambda_{\bar{u}u}$ = a coefficient of service agglomeration attractiveness (the existence of other services helps to attract customers also to the service being considered; $\lambda_{\bar{u}u}$ are parameters of the model and two cases, either all $\lambda_{\bar{u}u} = 0$ or $\lambda_{1u} = 0.2$, $\lambda_{2u} = 0.1$, $\lambda_{3u} = 0.067$, $\lambda_{4u} = 0.05$, $\lambda_{5u} = 0.04$ have been used in the simulations);

(*) $\alpha$ = the power coefficients of the influence of the distance $d_{xy}$ on the attractiveness; this is a parameter of the model ($\alpha = 2$ or $\alpha = 1$ have been used in the simulations);

(*) $d_{xx} \neq 0$ = a parameter of the model (the average distance that customers have to travel to obtain services in their own settlement; $d_{xx} = 0.4$ km has been used in the simulations);

(*) $D_0$ = the maximal distance that consumers would travel to obtain a service (two cases, $D_0 = 5$ km and $D_0 = 100$ km have been used in the simulations). Hence, the set $X_{D_0,x} = \{y \in X : d_{xy} \leq D_0\}$ can be interpreted as the set of settlements influenced by the service located at x, the attraction region of this service.

Then, the relative attractiveness coefficient

$$\eta^u_{xy,t} = \frac{A^u_{xy,t}}{\sum\limits_{\bar{x} \in X} A^u_{\bar{x}y,t}} , \qquad (22)$$

is determined, where x denotes alternative locations of services (including x). The coefficients $\eta^u_{xy,t}$ estimate the results of competition for customers of services between service location x and other locations. $\eta^u_{xy,t}$ can be interpreted as the proportion of customers from settlement y that would travel to location x for service u. It is assumed that (*) $q^u$ is the coefficient of demand for service u, measured by the number of employees in u per capita of the population, where two variants:

<u>Variant I:</u>

$$q^1 = 0.004,\ q^2 = 0.007,\ q^3 = 0.012,$$
$$q^4 = 0.017,\ q^5 = 0.020,$$

<u>Variant II:</u>

$$q^1 = 0.002,\ q^2 = 0.0035,\ q^3 = 0.006,$$
$$q^4 = 0.0085,\ q^5 = 0.010$$

have actually been used in the simulations. Then, the demand for service u at location x can be estimated by:

$$D^u_{x,t} = \sum_{y \in X} P_{y,t} q^u \eta^u_{xy,t} \quad . \tag{23}$$

If a small maximal distance $D_0$ has been assumed, then this estimate is, in a sense, conservative (slightly smaller than it could be), since in reality customers would travel a considerable distance to obtain certain types of services. On the other hand, this estimate is conservative only if it is assumed that the existing levels of services at other locations are not increased. On the whole, this estimate might be far too optimistic.

If $t > t_{uo}$ but $E^u_{x,t} = 0$ and the location x was selected in random generation procedures, the computations are repeated as in (21), (22), (23) under the hypothesis that service u is introduced at location x and at the minimal level $E^{uo}$, while in other locations the levels of service u remain unchanged. Thus, the hypothetical demand $\tilde{D}^u_{x,t}$ is determined by:

$$\tilde{A}^u_{xy,t} = \frac{E^{uo} + \sum_{\bar{u} \neq u} \lambda_{\bar{u}u} E^u_{x,t}}{d^{\alpha}_{xy}} \quad , \tag{24}$$

$$\eta^u_{xy,t} = \frac{\tilde{A}^u_{xy,t}}{\tilde{A}^u_{xy,t} + \sum_{x \in X} A^u_{xy,t}} \quad , \tag{25}$$

$$\tilde{D}^u_{x,t} = \sum_{y \in X} P_{y,t} q^u \tilde{\eta}^u_{xy,t} \quad . \tag{26}$$

After the estimate $D^u_{x,t}$ or the hypothetical estimate $\tilde{D}^u_{x,t}$ have been determined, the next period of employment in service u at location x is computed by an adaptive employment mechanism. The estimated employment increase $\hat{\Delta}^u_{x,t}$ results from:

$$\hat{\Delta}^u_{x,t} = \begin{cases} \tilde{D}^u_{x,t} \ , & \text{if } E^u_{x,t} = 0 \\ D^u_{x,t} - E^u_{x,t} \ , & \text{if } E^u_{x,t} > 0 \end{cases} \quad . \tag{27}$$

However, it is known that the estimates $D^u_{x,t}$ or $\tilde{D}^u_{x,t}$ may be too optimistic, because other locations might also increase their service levels. Therefore, the employment estimate $\hat{E}^u_{x,t+1}$ is adapted by using only a part $a$ of the increase $\hat{\Delta}^u_{x,t}$ (where $a$ is a parameter of the model and expresses the conservativeness of employment policy; $a = 0.5$ and $a = 1.0$ have been used in the simulations):

$$\hat{E}^u_{x,t+1} = E^u_{x,t} + a\hat{\Delta}^u_{x,t} \quad . \tag{28}$$

The estimate $\hat{E}^u_{x,t+1}$ could be used directly to determine future employment (which would result in the simple relation $\Delta^u_{x,t} = a\hat{\Delta}^u_{x,t}$). However, it has been assumed that it is not reasonable to introduce a service into a settlement whose employment level is below $E^{uo}$. Similarly, it is assumed that it is not reasonable to retain a service if employment decreases below $bE^{uo}$, $b$ being a parameter of closing down the service ($b = 0.5$ has been used in the simulations).

Thus:

$$E^u_{x,t+1} = \begin{cases} \hat{E}^u_{x,t+1} & \text{if } \begin{cases} E^u_{x,t} > 0 \text{ and } \hat{E}^u_{x,t+1} \geqslant b\,E^{uo} \\ \text{or} \\ E^u_{x,t} = 0 \text{ and } \hat{E}^u_{x,t+1} \geqslant E^{uo} \end{cases} \\ 0 & \text{if } \begin{cases} E^u_{x,t} > 0 \text{ and } \hat{E}^u_{x,t+1} < b\,E^{uo} \\ \text{or} \\ E^u_{x,t} = 0 \text{ and } \hat{E}^u_{x,t+1} < E^{uo} \end{cases} \end{cases} \quad . \tag{29}$$

Then, $\Delta^u_{x,t}$ is only defined by the identity:

$$\Delta^u_{x,t} = E^u_{x,t+1} - E^u_{x,t} \quad , \tag{30}$$

which is not used in actual simulations, because (29) can be used instead of (10) in order to determine $E^u_{x,t+1}$.

The question of the stability of this simulation model and of its steady-state solutions is rather complicated and will be treated here only approximately. If a linear adaptive employment mechanism, say $E^u_{x,t+1} = \hat{E}^u_{x,t+1}$, were used instead of the nonlinear switch characteristics (29), then the steady-state solutions $E^u_{x,t+1} = E^u_{x,t}$ would imply, first, $D^u_{x,t} = E^u_{x,t}$ by virtue of (27) and, second, a rather precise estimation of demand $D^u_{x,t}$ resulting from the constancy of $E^u_{x,t}$ for all x, u, t. Such a solution, characterized by a near equilibrium of supply and demand for services, is attainable only without random influences and only if $r = 0$ and $\delta^v_x = 0$, that is, without any population growth or industrial and intensive agricultural development. The stability of such a solution can also be analyzed. In such a version the model would be stable for sufficiently small coefficients $a$ and would probably remain stable for $a \lesssim 2$. This results from the following reasoning: the difference between the demand and supply $D^u_{x,t} - E^u_{x,t}$ depends mainly on the supply $E^u_{x,t}$ at the same location, since the inequality $d_{xx} \leqslant 0.1 d_{xy}$ for all other y implies that the influence of the supplies $E^u_{y,t}$ at $y \neq x$ for each y on the demand $D^u_{x,t}$ is rather small. Thus, the stability of the model can be analyzed approximately as the stability of independent equations

$E^u_{x,t+1} = (1 - a)E^u_{x,t} + aD^u_{x,t}$. If the partial derivatives $\dfrac{\partial D^u_{x,t}}{\partial E^u_{x,t}}$ are close to zero, then these equations are stable for $0 \lesssim a \lesssim 2$. As long as those partial derivatives are positive and do not exceed 1 (which can be concluded close to the equilibrium solution), the stability of these equations is only improved. However, with the nonlinear switch characteristics (29) and for a model with random influences, population growth, as well as industrial and intensive agricultural development, the questions of stability and of a quasi-equilibrium solution of the model are much more complicated. It can only be expected that the model remains stable for sufficiently small $a$ and for $b$ that are not too close to 1. An approximate stability analysis of the model with the switch characteristics (29) results in the stability condition $0 \lesssim a \lesssim (1 - b)$, although when $b \to 1$ and $a < 2$, the amplitude of the oscillations decreases. These expectations have actually been confirmed by simulation runs, in which the model exhibited strong oscillatory behavior for $b = 0.5$, $a = 1$, while for $b = 0.5$, $a = 0.5$ it remained stable. Naturally, the quasi-steady-state solutions of the model can correspond to somewhat larger disequilibria between supply and demand for services because of the switch characteristics (29).

## SIMULATION RESULTS

The above model has been used to simulate the development of a rural settlement pattern. Changes over time in the following characteristics of the pattern were observed: the number and size of service centers, the spatial coincidence of services, the spatial distribution of the population, and the stationarity of the composition of service centers.

The first change was measured by the average number of services. The second change was measured by the proportion of centers having a coincident cluster of services to the total number of centers (only centers having at least three coincident services were taken into account). The third change was measured by the coefficient of location. Finally, the stationarity of the composition of service centers was identified by the earliest date at which the composition ceased to change.

Seven settlement patterns were simulated, each case being defined by the parameters given in Table 1. The results of the simulation for the seven cases are given in Table 2.

Several general conclusions can be drawn from a glance at Table 2. As development advances, the number of service centers decreases but their size increases. This implies that development is accompanied by concentration. The relation between the number

Table 1. The parameters defining the seven settlement patterns to be simulated.

| SETTLEMENT PATTERNS | PARAMETERS | | | | | |
|---|---|---|---|---|---|---|
| | $\psi$ | $D_0$ | $\gamma$ | $\alpha$ | q* | $\delta$** |
| 1 | 1000 | 5 | 100 | 2 | I | I |
| 2 | 0.1667 | 5 | 100 | 2 | I | I |
| 3 | 0.1667 | 100 | 100 | 2 | I | I |
| 4 | 0.1667 | 100 | 0 | 2 | I | I |
| 5 | 0.1667 | 100 | 100 | 1 | I | I |
| 6 | 0.1667 | 100 | 100 | 2 | II | I |
| 7 | 0.1667 | 100 | 100 | 2 | I | II |

*I and II denote the first and second variants of the demand/employment ratio q.

**I and II denote the first and second variants of the coefficient $\delta$ determining employment in intensive agriculture and industry.

and size of centers in the simulated pattern is similar to that in Christaller's model only at an early stage of development. In later stages, larger centers are more numerous than smaller ones, which implies that the tendency in the simulated pattern deviates from that in Christaller's model. It is, however, consistent with the idea of the development of key villages and the decay of small service centers. The tendency also leads to the formation of a new hierarchical pattern characterized by the existence of several centers on the highest level instead of one center only (Figures 2, 3, and 4).

The coincidence of services is positively correlated with their concentration. The higher their concentration, the higher is their coincidence (Figures 5 and 6).

Table 2. The results of the simulation for the seven settlement patterns.

| SETTLEMENT PATTERNS | | Number of centers | Size of centers | Spatial coincidence of services | Spatial distribution of population | Stationarity of composition of centers |
|---|---|---|---|---|---|---|
| 1 | t=10 | 24 | 1.3 | 0.04 | | |
| | t=30 | 18 | 3.1 | 0.39 | | |
| | t=50 | 17 | 3.3 | 0.47 | 0.45 | t=40 |
| 2 | t=10 | 23 | 1.2 | 0.04 | | |
| | t=30 | 16 | 2.6 | 0.31 | | |
| | t=50 | 15 | 3.1 | 0.47 | 0.45 | - |
| 3 | t=10 | 20 | 1.3 | 0.05 | | |
| | t=30 | 11 | 3.4 | 0.55 | | |
| | t=50 | 10 | 4.3 | 0.90 | 0.45 | t=40 |
| 4 | t=10 | 23 | 1.4 | 0.09 | | |
| | t=30 | 13 | 3.6 | 0.62 | | |
| | t=50 | 13 | 3.6 | 0.62 | 0.45 | t=30 |
| 5 | t=10 | 21 | 1.3 | 0.05 | | |
| | t=30 | 9 | 3.2 | 0.56 | | |
| | t=50 | 7 | 3.9 | 0.86 | 0.45 | t=40 |
| 6 | t=10 | 15 | 1.3 | 0.00 | | |
| | t=30 | 9 | 3.0 | 0.56 | | |
| | t=50 | 8 | 3.9 | 0.75 | 0.45 | - |
| 7 | t=10 | 25 | 1.3 | 0.00 | | |
| | t=30 | 21 | 2.5 | 0.19 | | |
| | t=50 | 24 | 2.9 | 0.37 | 0.19 | - |

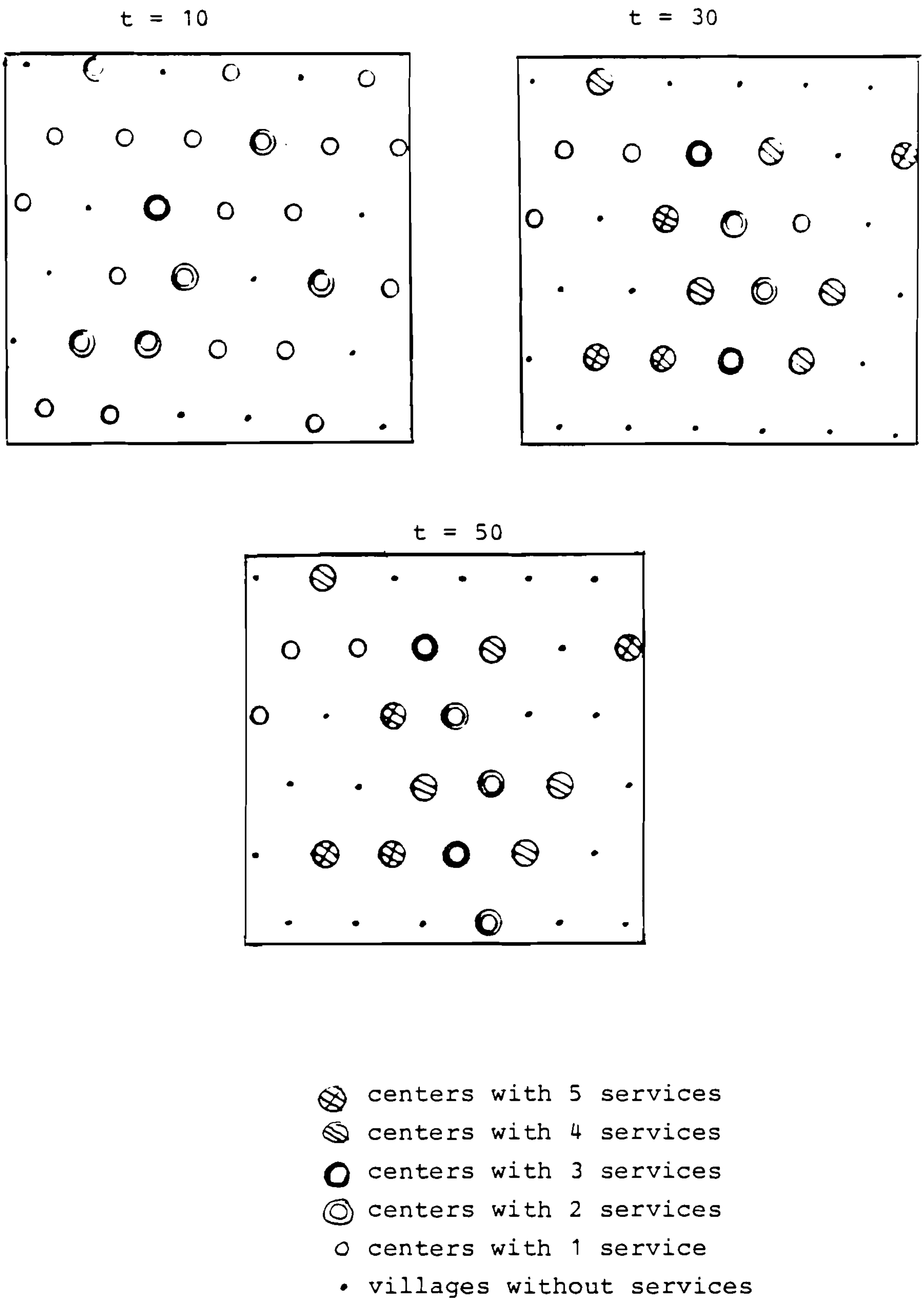


Figure 2. The sizes of service centers: case 1.

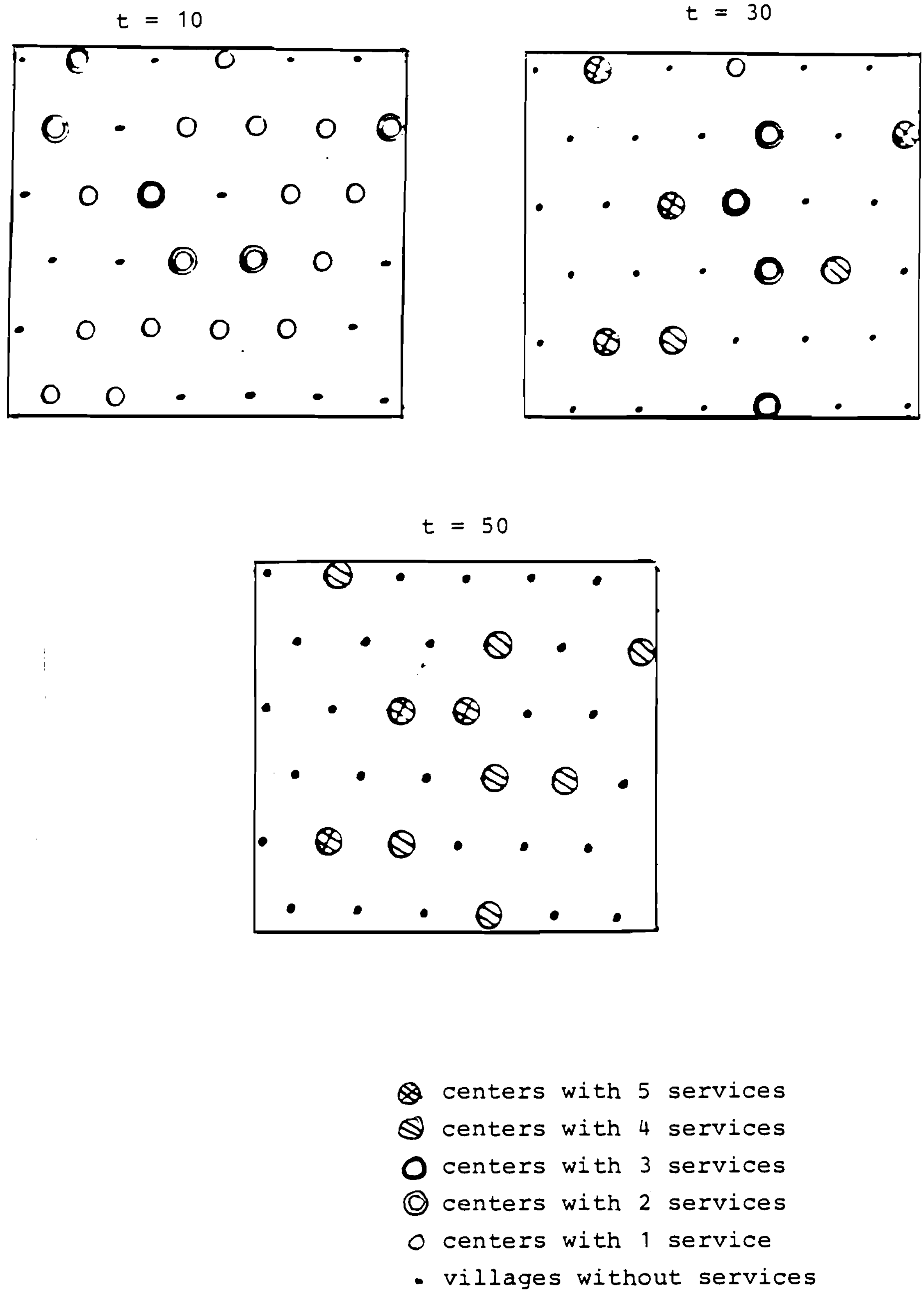


Figure 3. The sizes of service centers: case 3.

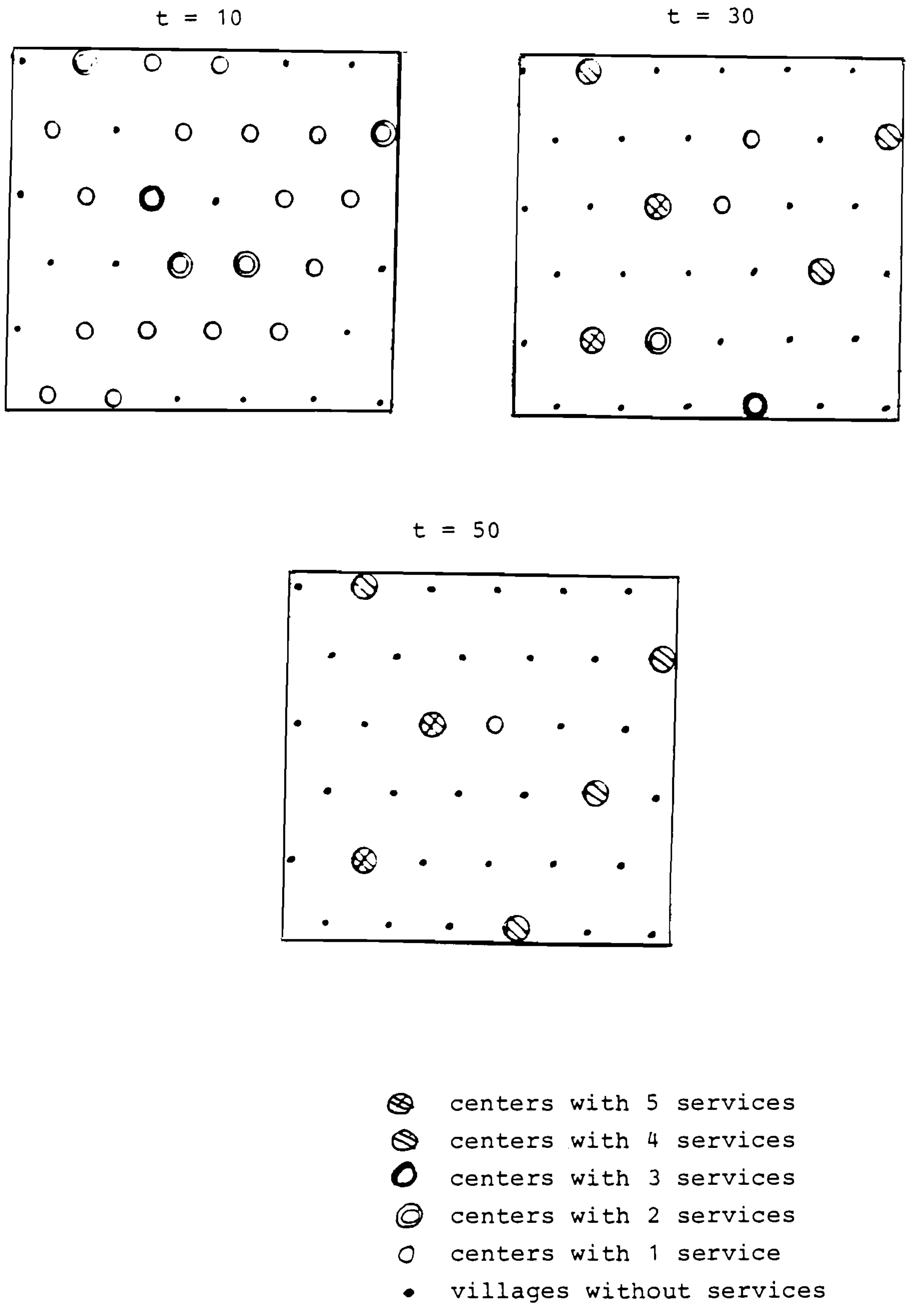


Figure 4. The sizes of service centers: case 5.

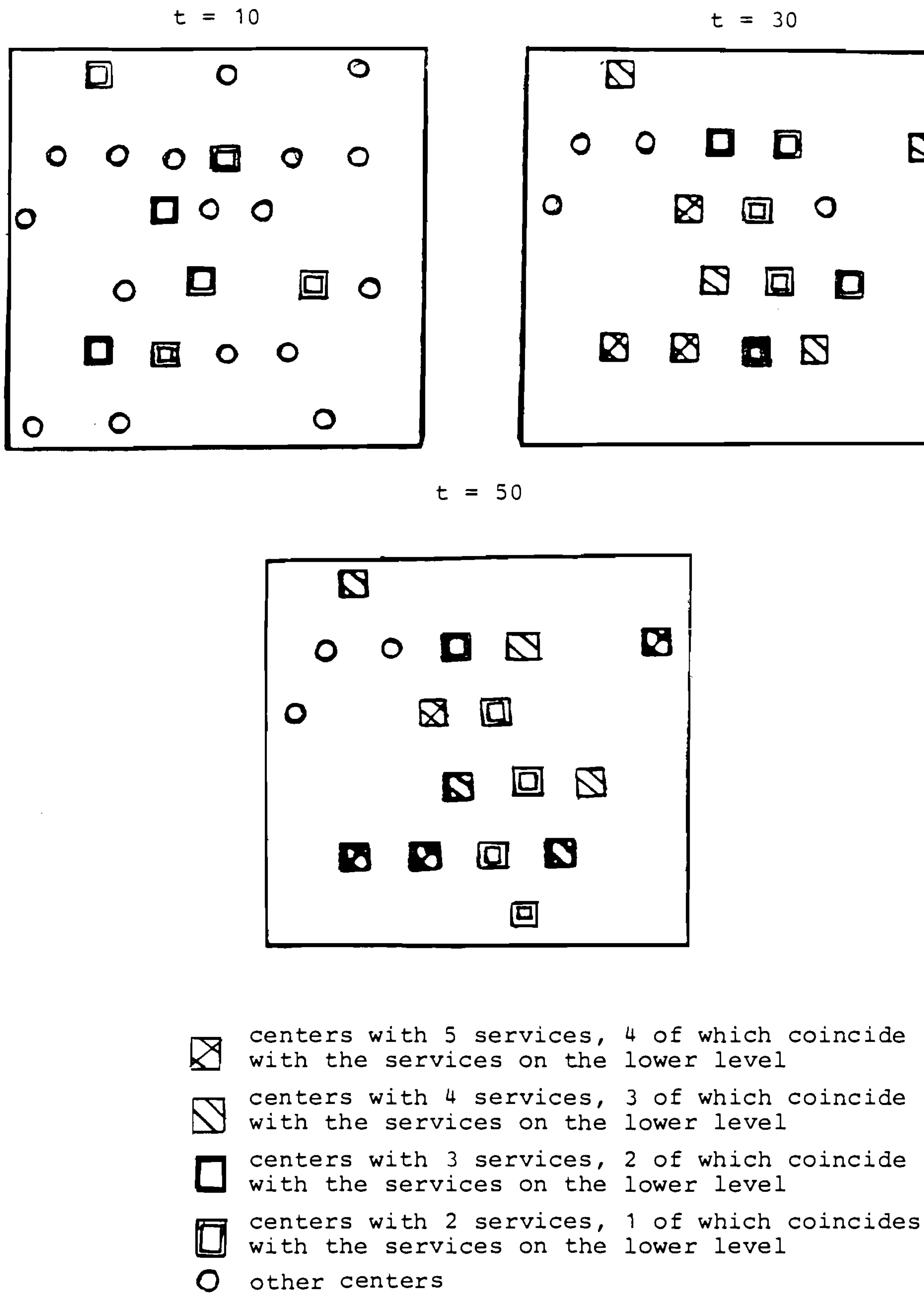


Figure 5. The spatial coincidence of services: case 1.

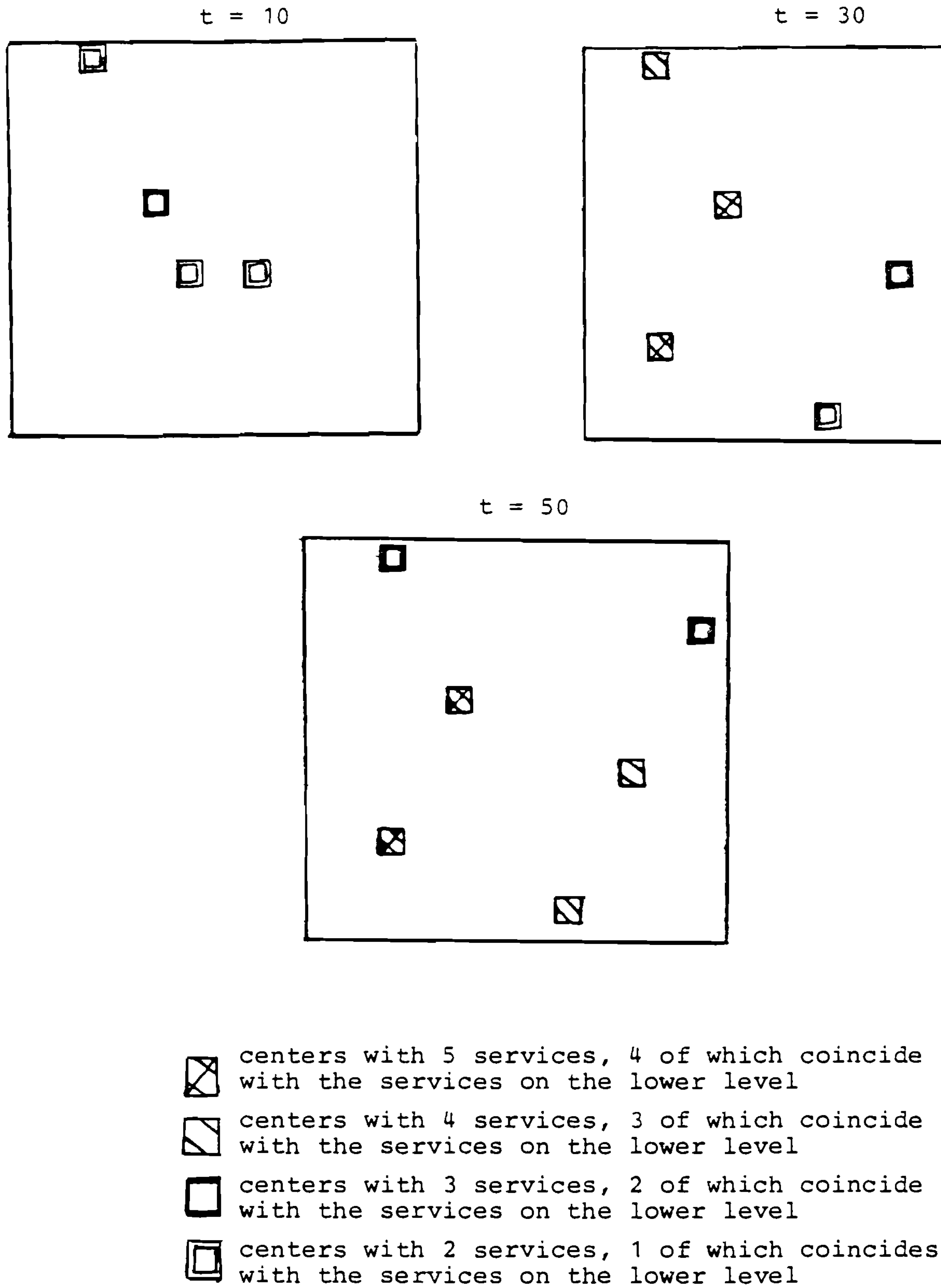


Figure 6. The spatial coincidence of services: case 5.

The spatial distribution of the population measured by the coefficient of location turned out to be the same in six cases for $t = 50$ (Figures 7 and 8). This result suggests that our settlement system exhibits a type of steady-state characteristic.

In four out of seven cases the composition of service centers does not change with time by the end of development period. In two further cases the changes are very small. Hence, it can be stated that the composition of service centers approaches a stationary state.

Let us now look at changes in the settlement-pattern characteristics resulting from changes in particular parameters in consecutive simulations.

Parameter $\Psi$ was used in a random selection of locations in which the introduction of services was considered. Two parameter values were assumed: $\Psi_2 = 0.1667$ and $\Psi_2 = 1000$. $\Psi_2 = 1000$ denotes the probability of service generation equal to 1, which means that each location x is considered as a center for service u, $\Psi_2 = 0.1667$ means that only one-sixth of locations is considered.

The assumption $\Psi_2 = 1000$, in comparison with $\Psi_2 = 0.1667$, resulted in a larger number and size of centers. The growth path showed a greater deviation, manifested by a larger number of opening and closings of services en route to the final state. Tne lowering of the probability of service generation appeared to be a limiting factor in the development process.

Parameter $\alpha$ was used to measure the influence of distance on the attractiveness of service centers. In case 5 its value was lowered from 2 to 1. The effect on the settlement pattern was marked. The number of service centers decreased considerably. At $t = 50$ only seven centers remained. These were mostly large centers. Small centers were pushed out almost entirely. Such a result is to be expected. The weakening of the friction of space allows long distance trips to be made in searching for attractive service centers. Usually, large centers are more attractive, whereas small centers lose customers and decline.

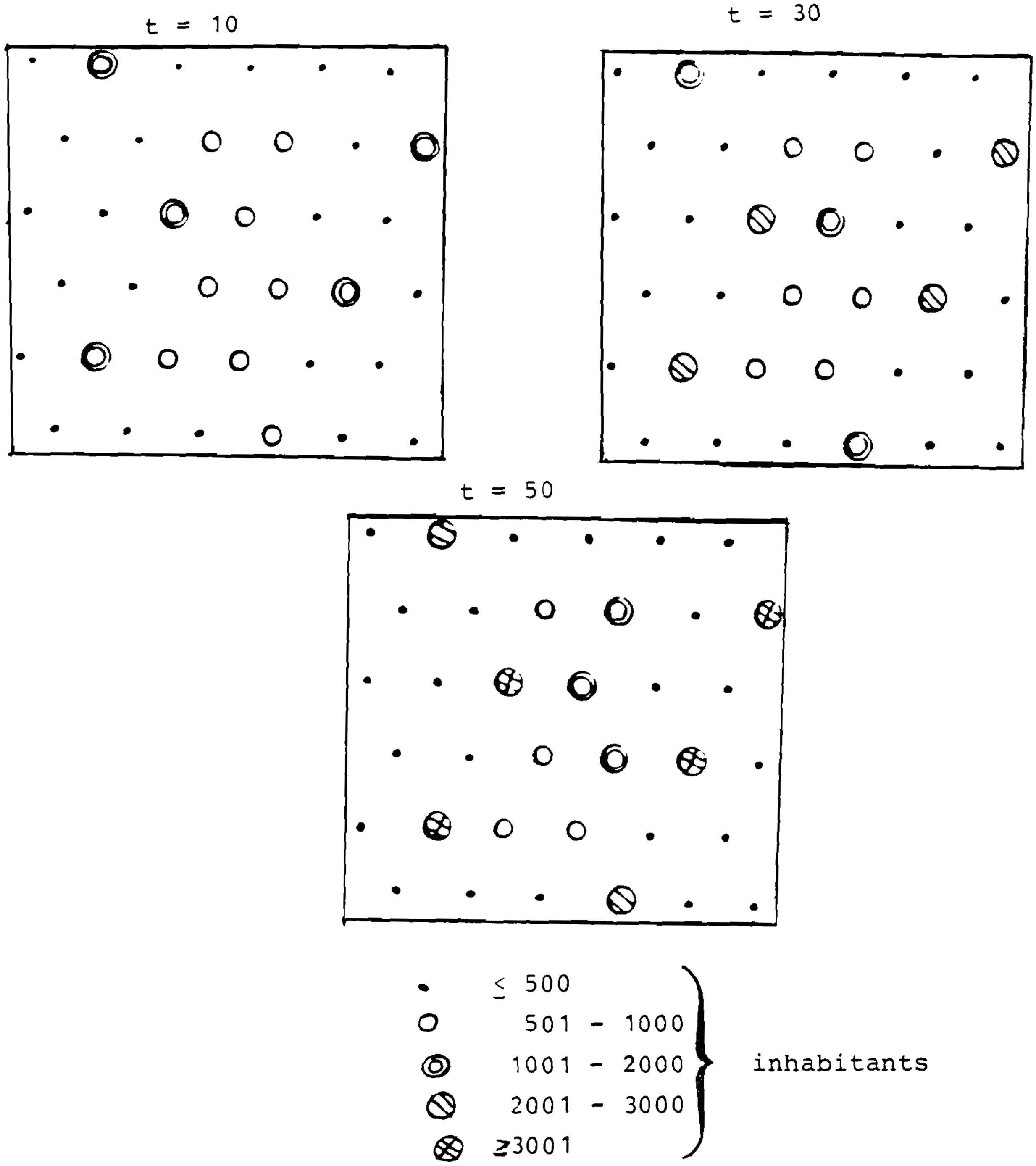


Figure 7. Changes in the spatial distribution of the population: case 3.

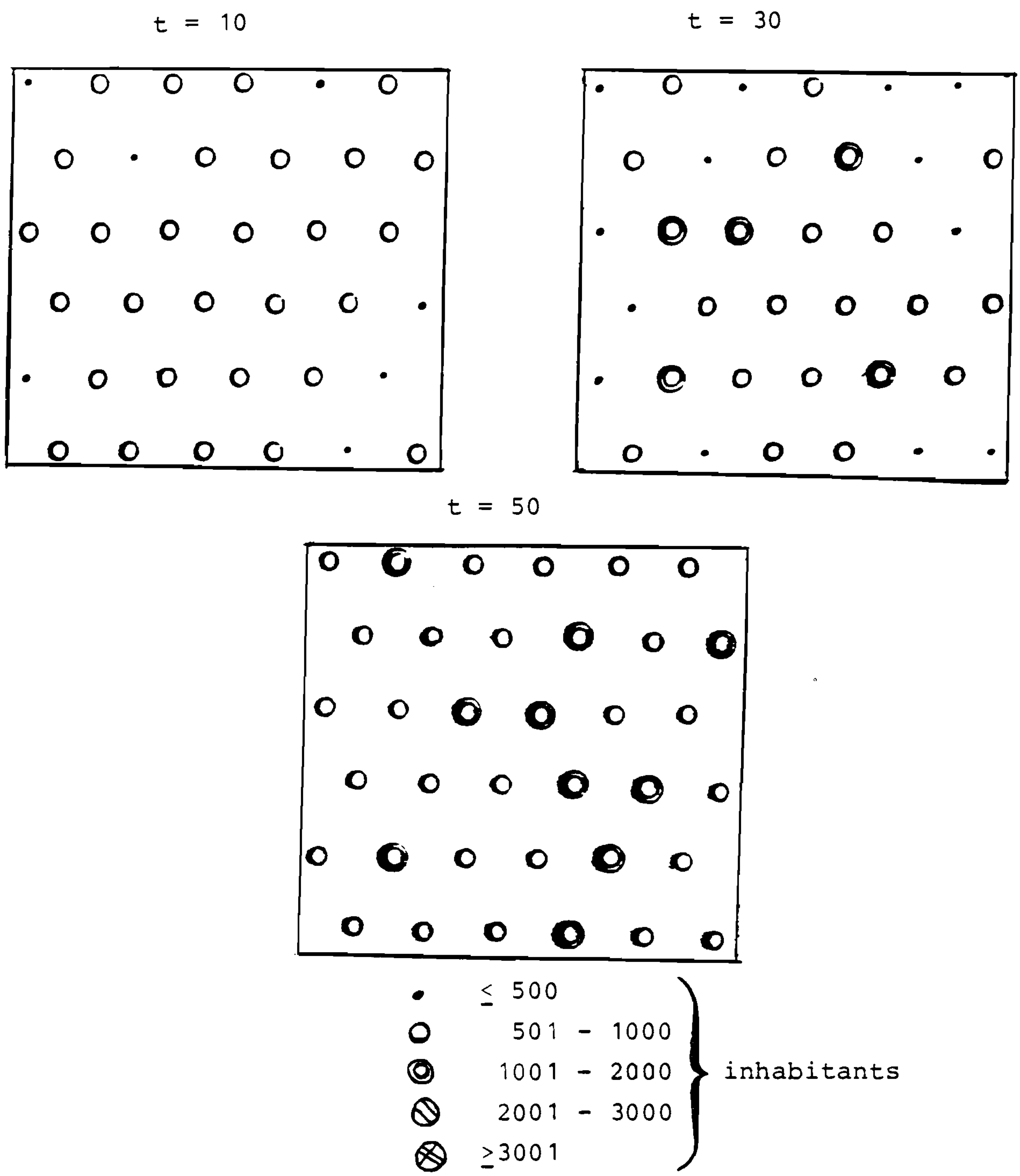


Figure 8. Changes in the spatial distribution of the population: case 7.

The change in the value of parameter $D_0$, denoting maximal distance that customers are prepared to travel to obtain services, caused a similar effect. After its value was increased from 5 to 100 km, the range of trips also increased. This improved the position of large centers and worsened the situation for small centers.

The existence of services introduced earlier, expressed by parameter $\gamma$, did not influence the simulation results in an explicit way. This can be explained by the fact that $\gamma$ influences only the selection of the locations for services and not the growth path of established service centers.

A strong agglomeration effect in the process of growth showed instead the existence of industry and intensive agriculture. It influenced the concentration of services, their coincidence, as well as the spatial distribution of population. The leveling down of employment in industry and intensive agriculture made the settlement pattern more dispersed.

The change in the value of parameter $q$, which denotes the demand for services, exerted an influence only on the number of centers, whereas the degree of concentration and coincidence as well as the spatial distribution of population did not show any reaction. The decrease in demand also resulted in a decrease in the number of centers needed to serve the population.

## CONCLUSIONS

The model generated a plausible picture of a restructured network of settlements in a rural area. The network of key villages obtained from the model may serve as a basis for settlement planning in rural areas.

The assumptions of the model stress a decentralized self-generating process of service development. In order to emphasize the planned introduction of services and their influence on settlement patterns, appropriate modifications would have to be introduced into the model. However, in principle, such modifications are possible.

The model proved to be sensitive to all defining parameters and can be used to obtain a set of projections under various assumptions about economic activities and population. Thus, various settlement policies for rural areas can be tested.

REFERENCES

Allen, P.M. and M. Sanglier. 1979. A dynamic model of growth in a central place system. Geographical Analysis 11(3): 256-272.

Domanski, R. 1980. Rural Settlement Patterns. WP-80-128. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Nicolis, G. and I. Prigogine. 1977. Self-Organization in Nonequilibrium Systems. New York: Wiley.