Network-Based Modelling and Geographic Information Systems

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One of the latest developments of the location theory envisages the territorial networks, which are considered the most complex type of clusters (compared to pure agglomeration and industrial district), more and more researchers concentrating on the systemic approach of these networks and the possibilities to develop adequate models for their analysis. The Geographic Information Systems represent one of the most useful tools in this respect. This paper proposes an inquiry into the network definition and typology, pointing out the possibilities to use the neural network- based models in order to study the territorial relationships. The role of Geographic Information System (GIS) as one of the instruments that can provide valuable information in data analyses is also considered.
Keywords: *network typology, neural networks, GIS.*

Introduction

Location theory is the oldest branch in regional economics and represents the substance from which regional science as a whole has subsequently rooted. It dates back into the nineteenth century, when the question about what economic activities are located where and why started getting a great importance to the production and the consumption choices made by firms and households.

Location theory has been permanently developed, combining microeconomic approaches based on firm location models (e.g. W. Laundhard (1885), A. Weber (1909), H. Hotelling (1929), L.N. Moses (1958), M.L. Greenhut (1970) and so on) with macroeconomic approaches focused on spatial distribution of economic activities (e.g. J.H. von Thünen (1842), W. Christaller (1933), A. Lösch (1940, 1944), W. Isard (1953), B. Chinitz (1961), R. Vernon (1966), H. Richardson (1978), P. Ayfdalot and D. Keeble (1988), M. Fujita and P. Krugman (1995) and so on). It has proved an extraordinary capacity to adapt to the new realities generated by the economic progress, offering adequate methodological framework of analysis and rational solutions to the more and more complex problems of the space – economy relationships. One of the latest developments of the location theory envisages the *territorial networks*, pointing out the need and advantages of integrating the business firms in a coherent framework, which creates links, relations, exchanges between them and other actors within the region (banks, universities, research institutes, training centres, consulting firms, chambers of commerce, associations of producers, local public administration). Territorial networks are considered the most complex type of clusters (compared to pure agglomeration and industrial district), more and more researchers concentrating on the systemic approach of these networks and the possibilities to develop adequate models for their analysis. The Geographic Information Systems represent one of the most useful tools in this respect. This paper proposes an inquiry into the network definition and typology, pointing out the possibilities to use the neural network- based models in order to study the territorial relationships. The role of Geographic Information System (GIS) as one of the instruments that can provide valuable information in data analyses is also considered.

Background

The networks can be defined in many ways, the terminology being used in various fields of activity such as chemistry, neurology, architecture, cybernetics. Today everything seems to be part of a network. Even if the network concept is widely used, clarifications are needed because everything gives the

impression of relations, connections, associations, cooperation, etc.
As a general definition, the network describes a process where two or more participants or groups of participants work for a common goal having the same vision. This process is not based on formal contracts, but on trust, partnership and the conviction that the interested persons will obtain benefits (Sprenger, 2001).
The specific literature illustrates that networks are not only specific structures, spatially organized, but are also providing functions that aim to improve the efficiency of spatial interactions. According to Batten (1994), but also to Reggiani şi Nijkamp (1996), the network can be defined as a complex socio-temporal system. Thus, the network is a spatial-economic or socio-economic system characterized by evolutional processes governed by multiple players, interdependent organizations of subsystems. An hierarchical system is just a special case of a more general distribution of a network (Reggiani, Nijkamp, Sabela, 2001).
Tijssen (1998) defines the network as being "an evolutional system of mutual dependency based on relations between resources, the systemic character being provided by the results of interactions, processes, procedures and institutionalization" (p.792). The resources needed for activities within such a network are combined, changed, transformed, absorbed based on formal and informal relations. According to Fischer (2006) the network resources are represented by different types of capacities, competences and goods that can be divided into tangible resources (codify knowledge) and intangible resources (know-how, experience, personal contacts).
Also, the international literature, influenced by the practical experience in regional development defines the territorial network as *local cooperation between firms (usually small and medium enterprises), banks, research institutes, universities, consultancy centers, chambers of commerce and industry, associations of producers, public administration and other social interested groups* (Maillat, 1990, Cappellin, 1998, Sprenger, 2001).

Network typology
The relations within network are developed in time, nevertheless once formed are characterized by a high interdependency, communication, reciprocity and trust. However, within the network, not only resources are important, but also the actors. Fischer (2006) considers that the contacts between the networks' actors are influenced not only by the market relations, but also by the social and cultural context, especially the social and cultural rules, conventions, traditions that law the organizations interactions.
The international literature reveals that network characteristics differ according to technology and innovation types, industrial sector, regional and national environment. In the same way are varying the network types.
According to relation development, Fischer (2002) identifies two types of networks: one based on *vertical collaboration*, very common within production cycles, and the other one based on *horizontal collaboration* between partners at the same level of production process.
Taking into account the relations within the network, there have been identified:
- Networks with *internalized relations* characteristic to the research-development process, design, engineering.
- Networks with *externalized relations* characterized by relational structures within independent firms, based on a high rate of confidence and time to develop. (Fischer, 2002)

The types of externalized relations can be different according to the actors involved. Thus, informal and formal networks have been identified. The *formal networks* are characterized by partnership between firms based on written agreements for distribution of technologies and achievement of objective, without an equal distribution of the benefits. The *informal relations* are based on a high level of confidence between two parts involved: researchers and laboratories of different institutions. The objectives of these relations are to obtain research products with low cost of trading.

Between the involved parts of a network, respectively individuals and institutions, are established relation based on reciprocity, preferences and support, so that the resources allocation within the network is distributed according to this and not performed through direct relations or administrative rules.
Taking into account the networks definitions, Cappellin (1998) and Orsenigo (2000) consider that *within a local production system* are developed the following types of networks:

- Technological, encouraging the development of production technologies, dissemination of knowledge and values, technological cooperation between firms.
- On labour market, envisage the labour force mobility between firms working in the same area of activity.
- Production, subcontracting relations between firms, contributing to local production diversification.
- Services, encouraging the dissemination of modern techniques applicable in these areas.
- Financial, capable to concentrate large amount of money, to promote spin-off creation, to attract important external investments.
- Territorial, having impact on improving transport infrastructure, public endowments, territorial planning.
- Social and cultural, influencing the existence of local identity and getting the consensus on development strategy of the community.
- Institutional, aiming to develop the local administrative capacities in order to interact with regional/ national level institutions for implementing the development strategy of the community.
- Interregional and international, contributing to business internalization.

Camagni (1995, quoted by Cappellin, 2000) classifies the networks taking into account the geographical distance between members. Thus, there are:

- *Local networks* influenced by the cultural, spatial and psychological models that determine the development of informal relations.
- *Inter-territorial networks*, characterized by a geographical separation that determines partnership relations based on a regular and low intensity communication.

The complex socio-economic system represents a challenge to the people working in the field of forecasting. The majority of economic interventions, for examples the distribution of the structural and national funds, need to be underpin on analysis at various administrative levels (national, regional, county) so that to allow the selection of the most appropriate decision by taking into consideration of all variables that can contribute to achieving the policies objectives. In this case the level of data collecting is very important, the decision making process being influenced by the quantity of observations available.
The capacity of neural networks of analyzing data and realizing functional relations between variable, makes it possible the elaboration of strict statistical hypotheses and specific problems, but also the data processing through flexible statistical instruments. (Patuelli, Reggiani, Nijkamp, 2006)

Neural networks and Geographic Information Systems

The use of modern systems and methodological approaches can offer solution for various spatial data problems. Geographic Information System (GIS) is one of the tools that can provide valuable information in data analyses. GIS can be defined as a digital computer application designed to capture, store, operate and display spatially reference data, for solving complex research, planning and management problems (Fischer, 2006). The system is shaped by a database of spatially reference data used with appropriate software and hardware components.
The GIS system consists of a core component that includes the database, a spatial expert system and an artificial neural network. The system functions based on algorithms, mathematical and statistical models processed by the artificial neural networks and system rules according to the expert system component.
The expert system component achieves ex-

pert-level performance using symbolic representation of knowledge, interference and heuristic search. The expert systems can be applied in the following GIS areas: automated cartographic procedures for display, automated device routines for processing data and object structure, coupling expert systems and specific spatial analysis and model tools.
According to the Hecht – Nielsen (1990, quoted by Fischer, 2006) the artificial neural network can be considered as a dynamic system having the topology of a direct graph, where the nodes are processing elements and the directed links are termed connections. The communication between the processing elements is done through numerical signals. Moreover, the neural networks can be defined as modern statistical instruments based on learning algorithms capable to process a big number of data (Patuelli, Reggiani, Nijkamp, 2006). The neural networks are used more and more often in different fields of knowledge due to efficiency in a complex processing of data when the functional relation between the independent variables and the dependent one are not explicitly specified. Also, the artificial neural networks are optimizing algorithms having as main characteristic the ability of finding the optimal solution when the relation between variables are not sufficient known or explained, or when only a part of information on the phenomena are available. (John, 1999)
There is no general accepted definition of these types of systems, but most of the researchers consider the artificial networks as networks of simple elements strongly interconnected by relations, nodes through which the information circulates. Neural networks are often compared with conventional statistical methods, such as liner models or simple regression, because of an integrated utilization of all these methodologies.
The tasks performed by artificial neural networks are done by specifying the number of processing elements, the network topology and the strength of each connection. The elements are organized as a hierarchical series of levels: an input level, one or more intermediate levels (also known as hidden levels) and an output level. A network can function as a single entity with relation characterized by (Cappellin, 2000):

- The relations between two networks have a specific direction due to existing dependence.
- Every node of the network has a specific function.
- The existence relations within the network depend on the relations with another network.
- The evolution of the existence relations within the networks depends on the network history.

From the typological point of view, a *neural network* is a system that receives *input data* (corresponding to the initial data of the problem) and produces *output data* (that can be considered as answers to the analyzed problem). A very important characteristic of the neural networks is their capacity of adapting to the informational environment corresponding to a given problem thorough a learning process. This way, starting from examples, the network finds the model of the problem.
From structural point of view, a neural network is a *system of interconnected units* with simple functioning. The performance of the units is influenced by adjustable parameters, the neural network being in fact an extremely flexible system. The structure of the processing units, the relations and the adjustable parameters, as well as the functioning is inspired by models of the human brain. Every processing unit receives input signals that are processed and produces an output signal.
The main elements of the neural networks are (Cappellin, 2000, Fischer, 2006):

- *Architecture:* specifies the location and interconnections of the processing units; the architecture determines also the informational flow within the network.
- *Functioning:* shows the method through which every unit and the all network process the input signals into output ones; it is influenced by the unit interconnectivity.
- *Learning:* illustrates the adjustable parameters so that the network can solve the problems. Taking into consideration the information available, two type of training can be

distinguished: *supervised training* (where the network is supplied with a sequence (x_k, y_k) of input data x_k and target data y_k, and it is told what should be emitted as output) and *unsupervised training* (where the network is given only input data and uses no external influence to adjust its weights) (Fischer, 2006).

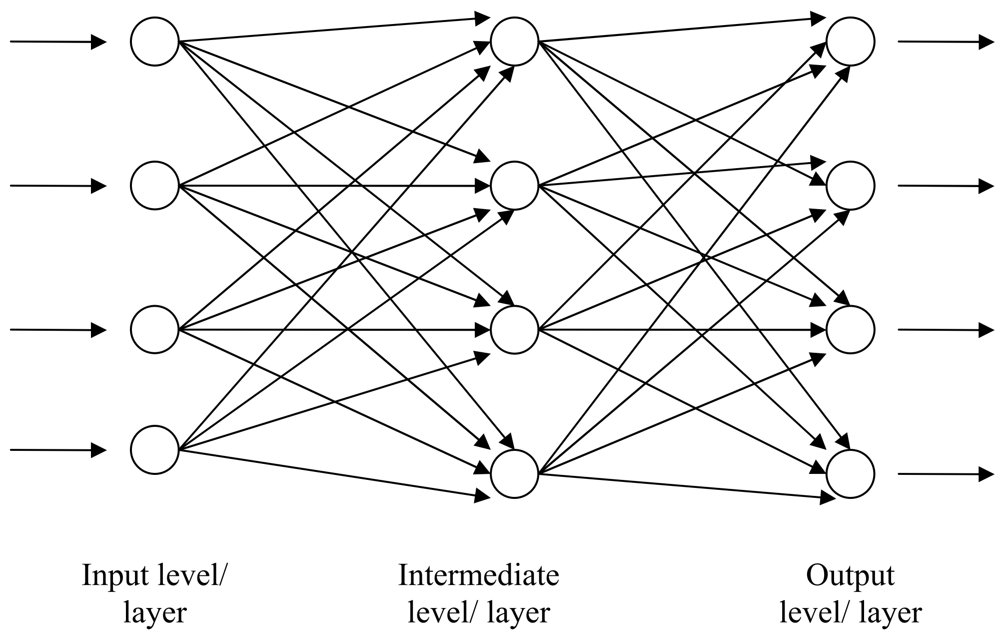

Fig.1. A feed-forward neural network with three fully interconnected layers
Source: M. Fischer, 2006, p.70

The heart of GIS is considered to be its data model, Fischer (2006) and John (1999) developing mathematical models of artificial neural network.
Thus, the figure above describes an example (Fischer, 2006, p.70-71) of a typical processing unit ***i*** at the level k+1 (k>1) of a multilevel ed network. For a processor ***i*** in level k+1 (k>1), the net input is

$$net_i^{k+1} = \sum_j \mu_{ij}^k o_j^k$$

μ_{ij}^k are the connection weights between levels k and k+1 and o_j^k the output of processor j from level k. The output o_i of each processor ***i*** at an intermediate level (k+1) is a continuous function of its net input net_i

$$o_j^{k+1} = f(net_i^{k+1}) = f\left(\sum_j \mu_{ij}^k o_j^k\right)$$

the nonlinearities are located in the activation (nonlinear transfer) function $f(net_i)$ of the hidden units. The $f(net_i)$ levels off and approaches fixed limits for large negative and positive nets. In that case o_j^{k+1} will always remain between those limits. One particular functional structure while is often used is the sigmoid shaped function for a (0,1) range

$$o_j^{k+1} = f(net_i^{k+1}) = \frac{1}{1+\exp-(-\beta net_i^{k+1})}$$

where β is an adjustable gain parameter which controls the steepness of the output transition. The last equation is known as a logistic function and $\beta = 1$.
Callopy (1994, quoted by Patuelli, Reggiani, Nijkamp, 2006) considers that evaluation and the comparison of the neural networks can be realized by respecting the following rules:
- The comparison with the conventional accepted models; the prognosis obtained by using the neural network model must be at least as good as the one generated through conventional methods.
- Testing the model performance; it can be use for comparing different methodologies.

• Using an appropriate sample; the size of the sample must allow statistical interferences.

Neural networks can be considered a viable technology, but accordingly to M. Fischer (2006) should be taken into consideration some problems that might occur, respectively: the danger of overfitting, the lack of standard development methods, demanding processing requirements and integration issues.

Concluding remarks

The GIS researchers consider that there are three major constraints of the system, respectively:

▪ Logical foundation, because the system needs artificial precision for imprecise spatial data, phenomena and processes (Leung, 1992, quoted by Fischer, 2006) that might influence the final result of the analysis.

▪ Limited analytical and modelling functionality because the GIS provides the storage and graphical display without taking into consideration methods that can improve its functionality, for example: spatial interaction and choice models, location-allocation models, space-time statistical models (Fischer and Nijkamp, 1992).

▪ Low level of representation and processing without taking into consideration the complexity of the geographical problems that need large data based and well structured information.

Based on these system limitations, Fischer (2006) identifies three elements that should be taken into consideration on the next generation of intelligent systems:

▪ the concept of fuzzy logic;

▪ advanced spatial analysis and models;

▪ artificial intelligence technology and, especially, artificial neural networks.

The big potential of neural networks can be valorized not only in the informatic systems, but also in other sciences that can use the geographic information system as a research tool.

The applications using neural networks have been designed and used in areas of activities, such as: image analysis, automated diagnosis, speech analysis and generation, including translation and automated speed recognition. (Fischer, 2006)

In the last decade, considering the need of correlation between different classes of data, respectively images and space-time series, the artificial neural networks have been recognized as being very useful for solving pattern recognition problems and also for analyzing spatial data. The range of potential applications, especially in the field of geographic information processing, is impressive. M. Fischer (2006) identifies some applications areas of neural network, such as: exploratory spatial data and image analysis, homogeneous and functional regional taxonomic problems, spatial interaction and choice modeling, optimization problems, space-time statistical modeling.

The complex decision environment of today's world makes the decision process more difficult, therefore the information obtained with geographic information systems can offer an alternative for the policies analysis and provide the efficient solution to spatial decision making problems.

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