

A FUZZY COGNITIVE MAP FOR HOUSING DOMAIN

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ABSTRACT

It is well known that local officials in city governments need to develop a comprehensive housing policies to guide their current and future decisions in the context of a specific community that often face different issues. In this paper, the authors propose an original Fuzzy Cognitive Map (FCM) model for housing domain; it analysis the housing decisions and identifies the reasons motivating people's residential choices. The model uses ten variables grouped into three categories. Stakeholders, including the authorities, could exploit the model to make scenarios and use these in order to develop strategies and policies that can lead to the improvement of households' life quality.

Keywords: fuzzy cognitive map (FCM), simulation, participative decision-making process, housing domain

1. INTRODUCTION

One of the main concerns of authorities, at international, national and local level, is to increase the quality of life of the citizens. Studies show that the households' residential choice is directly linked to the well-being of the community they belong to. Therefore, decisions makers are actively involved in developing projects with the objective of identifying the factors that positively or negatively influence people's quality of life.

Housing location is an interesting topic, because the decisions of households to move or stay in their residential location are determined by several issues such as: population density, property and rental cost, job availability, access to education, access to recreational activities and services and so on. All of these factors are closely tied to people's decision to live in a certain community.

In order to find the motivation of a household to relocate or stay in its current location, the main variables that influence the location choices have been identified first. Considering these factors as the main drivers of residential choice, a Fuzzy Cognitive Map model for housing was designed. Fuzzy cognitive maps are qualitative models of a system, designed through a participative process.

Once the variables of the housing model were identified, the next step consisted in defining the causal relations between them. For visualizing and analyzing the model two software tools were used: FCMapper[*] and Pajek[**]. Using FCMapper, the steady state of the system was calculated starting from the weighted matrix of the model. In order to see the

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impact a minor change of one factor could have over the other variables, the suggested FCM model was used to run two scenarios.

The advantage of FCMs is that they are very intuitive and therefore, they can be used by all citizens (even with less experience in the domain) in participating and understanding the decision making process in a certain domain.

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2. FUZZY COGNITIVE MAPS

Overview

Fuzzy Cognitive Maps (FCMs) are qualitative models of a system, consisting of variables (or concepts) and the causal relationships between those variables. The variables could be the actors, events, facts, or other entities which influence the described system. The causal relationships are floating numbers between 0 and 1, reflecting the relative strength between two variables. The cognitive maps can be graphically represented by a weighted graph, where the nodes are the variables, while the arcs are the causal relationships. The direction of an arc is decided by the direction of the corresponding causal relationship. The stronger is the causal relation, the greater (closest to 1) is the weight of the corresponding arc. The weak is the causal relation, the smaller (towards 0-value) is the weight of the corresponding arc.

Modeling systems using FCMs presents several advantages. FCMs are capable of participative process; they reflect the vision shared by politicians, officers, key partners, stakeholders and communities. They are very intuitive, easy to understand and use by non-specialists in the targeted domain.

FCM can be used to simulate the evolution of the system in time. Given an initial state of the system, a FCM can evolve over time until it reaches a state of equilibrium (the steady state). This steady state can be used to make predictions or to test different scenarios: fine modifications of one or several factors in the system will yield to different behaviors in time.

Formally, a FCM is a set of valued concepts and causal relationships:

$\{A, C, W\}$, where:

- N is the number of concepts;
- $A = (A_i) \ i = 1, \dots, N$ is the set of concepts;
- $C = (C_i \in [0, 1]) \ i = 1, \dots, N$ is the set of values for the concepts;
- $W = (W_{ij} \in [-1, 1]) \ i, j = 1, \dots, N$ is the set of weights (W_{ij} is the causal link/relationship between the concepts A_i and A_j).

The life-cycle of a Fuzzy Cognitive Map

The life-cycle of a FCM consists of three significant stages:

- (1) Designing the Fuzzy Cognitive Map
- (2) Running the Fuzzy Cognitive Map
- (3) Simulating scenarios

(1) Designing a Fuzzy Cognitive Map

There are several ways of designing the FCM:

- from questionnaires;
- through interviews conducted by a trained moderator (a specialist in FCMs);
- by data-mining, through extraction from written texts (possibly from social-media).

The causal relationship between factors is usually defined following the steps:

- a direct or inverse relation between two factors is identified; it is marked with an arrow pointing the direction of the relation;
- then, the strength of the relation is described, using linguistic (qualitative) weights, such are: “strong”, “weak”, or “lack” “low”, “medium”, “high” etc.;
- the linguistic weights are transformed into fuzzy sets (Table 1).

Fuzzy weights	Linguistic weights (How strong is the relationship?)
1.00	strongest
0.80	very strong
0.70	strong
0.60	moderately strong
0.50	weak
0.40	very weak
0.20	weakest
0.00	lack

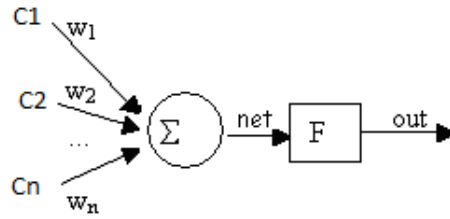
Table 1. Transformation of the linguistic weights into fuzzy weights

(2) Running a fuzzy cognitive map

As mentioned above, one of the advantages of FCMs is that they can be run until they reach a steady-state, which can be used for predictions, simulations, in order to obtain a better understanding of the process by people involved, not necessarily specialists.

Running a FCM is a process similar to training neural networks. In fact, the similitudes are perfect: the FCM consist in a set of nodes/concepts with initial values (time $t=0$), the nodes are linked between them with weighted arrows. We can compute a node's output with a process similar to activating a neuron: if $C_1, C_2, \dots, C_n$ are the concept values of all concepts that influence the focused factor with the weights $W_1, W_2, \dots, W_n$, then the output of the

focused node is obtained by summing the weighted factors and, applying a non-linear transformation (function F, named activation function) to this sum:



The summing operation in the above figure is “the activation of a concept node”. It involves multiplying each input causal influence C_i arriving from another concept node i , with the weight or strength, W_i , of the corresponding causal link:

$$net = \sum_{i=1..n} in_i * w_i$$

$$out = F(net) = F\left(\sum_{i=1..n} in_i * w_i\right).$$

The role of the activation function is to limit the amplitude of the output of a node to the interval $[0, 1]$. Literature specifies many forms of the activation functions, but the most commonly used activation function is the sigmoid function.

At each step, the value of a concept is influenced by the values of concept-nodes connected to it, until the system would converge to a point and no further changes would take place. So, running a FCM means iterating the FCM (repeatedly computing the values of the concepts) until the system converges to a steady state. Therefore, a FCM can simulate the system’s evolution over time to predict its future behavior.

(3) Simulating scenarios

Simulating scenarios is, in fact, the most interesting feature of FCMs. Simulating scenarios helps the decision maker to “predict the future”, and also explains to the beneficiaries (households and s.o.) why some decision have been taken. In scenario analysis, FCMs indicate the direction in which the system will move given certain changes in the driving variables. The scenarios do not offer any indication about the time axe (they are not able to predict the moment when something will happen), but they give an idea of the magnitude of system fluctuations after a disturbance.

3. A FUZZY COGNITIVE MAP MODEL FOR HOUSING ISSUE

Developing the FCM model

In this section, a Fuzzy Cognitive Map for the Housing domain is proposed. It is based on some features that characterize the quality of housing through social, demographic, economic, and facilities factors.

The model comprises ten factors grouped in three categories:

- 1) The housing relevant factors:
 - Owned housing
 - Rental cost
 - Property cost
 - Available land
- 2) The socio-economic and demographic:
 - Population
 - Schools
 - Employment
- 3) Accessibility to facilities:
 - Secondary facilities
 - Recreation facilities
 - Service facilities

For the factors included in the model the following causal relationships between them have been identified:

- Property cost has negative influence over Owned housing, Secondary facilities and Service facilities
- Owned housing has negative influence over Available land
- Available land has negative influence over Property cost
- Population has positive influence over Owned housing, Rental cost, Recreation facilities, Service facilities and Schools
- Rental cost has positive influence over Owned housing
- Secondary facilities, Recreation facilities and Service facilities have positive influence over Employment and negative influence over Available land
- Schools has positive influence over Employment

Based on the identified causal relationships the weighted matrix associated to the model was defined:

	Secondary facilities	Employment	Property cost	Owned housing	Available land	Population	Rental cost	Recreation facilities	Service facilities	Schools
Secondary facilities	0.00	0.60	0.00	0.00	-0.80	0.00	0.00	0.00	0.00	0.00
Employment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Property cost	-0.40	0.00	0.00	-0.80	0.00	0.00	0.00	0.00	-0.40	0.00
Owned housing	0.00	0.00	0.00	0.00	-0.50	0.00	0.00	0.00	0.00	0.00
Available land	0.00	0.00	-0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Population	0.00	0.00	0.00	0.30	0.00	0.00	0.20	0.40	0.20	0.80

Rental cost	0.00	0.00	0.00	0.40	0.00	0.00	0.00	0.00	0.00	0.00
Recreation facilities	0.00	0.70	0.00	0.00	-0.20	0.00	0.00	0.00	0.00	0.00
Service facilities	0.00	0.80	0.00	0.00	-0.40	0.00	0.00	0.00	0.00	0.00
Schools	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

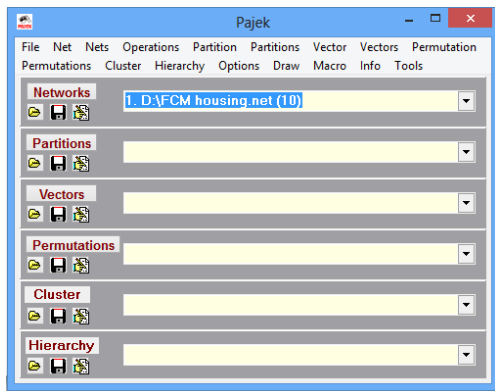
Table 2. The weighted matrix

The visual representation of the FCM model

For a better visualization of the FCM model, two freely available software programs have been chosen:

- FCMapper[*] – is a software tool for analyzing fuzzy cognitive maps, that can be used to automatically calculate the indices associated to the factors, to perform the dynamic simulations on the given model, and to transform the FCM model (coded in matrix format) into a file that can be further used in other network-analysis software tools.
- Pajek[**] – is a software package for visualization and analysis of large networks and provides a set of tools for analyzing such networks.

The digraph associated to the model was drawn using Pajek. The software tool provides six types of objects that can be used as input for network analysis: networks, partitions, permutations, clusters, hierarchies, and vectors. The networks are the main objects (vertices and lines) used for drawing the graph. A network can be given in an input file in different ways: using arcs/edges, using arcs-lists/edges-lists, or in matrix format. The input file can contain additional information necessary for drawing the graph such as the coordinates of each vertex or the color of the arcs.



(a)

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*vertices 10
1 "Secondary facilities" 0 0 0 ellipse x_fact 1.80 y_fact 1.80 ic Yellow
2 "Employment" 0 0 0 ellipse x_fact 2.40 y_fact 2.40 ic Yellow
3 "Property cost" 0 0 0 ellipse x_fact 2.00 y_fact 2.00 ic Yellow
4 "Owned housing" 0 0 0 ellipse x_fact 2.00 y_fact 2.00 ic Yellow
5 "Available land" 0 0 0 ellipse x_fact 2.30 y_fact 2.30 ic Yellow
6 "Population" 0 0 0 ellipse x_fact 1.90 y_fact 1.90 ic Yellow
7 "Rental cost" 0 0 0 ellipse x_fact 0.60 y_fact 0.60 ic Yellow
8 "Recreation facilities" 0 0 0 x_fact 1.30 y_fact 1.30 ic Yellow
9 "Service facilities" 0 0 0 ellipse x_fact 1.80 y_fact 1.80 ic Yellow
10 "Schools" 0 0 0 ellipse x_fact 1.10 y_fact 1.10 ic Yellow

*arcs
1 2 0.60 c Black
1 5 -0.80 c Red
3 1 -0.40 c Red
3 4 -0.80 c Red
3 9 -0.40 c Red
4 5 -0.50 c Red
5 3 -0.40 c Red
6 4 0.30 c Black
6 7 0.20 c Black
6 8 0.40 c Black
6 9 0.20 c Black
6 10 0.80 c Black
7 4 0.40 c Black
8 2 0.70 c Black
8 5 -0.20 c Red
9 2 0.80 c Black
9 5 -0.40 c Red
10 2 0.30 c Black
```

(b)

Figure 1. The network file (b) imported in Pajek (a)

The input network file for the current model was created using FCMapper. Starting from the adjacencies matrix, after defining the sets of vertices and arcs, the net file of the model was generated (Figure 1 (b)). The network file was then imported in Pajek and the associated digraph was drawn.

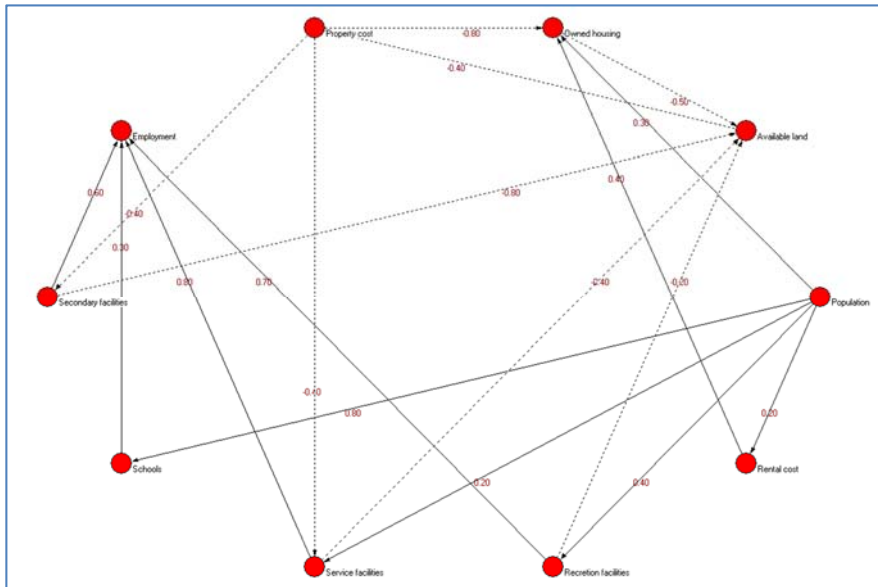


Figure 2. The digraph of the FCM model

In the above digraph, the causal relations between factors are represented using directed links between the corresponding vertices. A positive casual relation between two factors (drawn as a solid line) shows that increasing the first factor leads to an increase in the second factor. A negative relation (drawn as a dotted line) means that increasing the first factor generates a decreasing of the other factor.

Analysis of the FCM model

Given an initial state of the system, represented by a set of values of its constituent concepts (which are arbitrary, with no meaning, like the initial values for the weights in neural network), a FCM can evolve over time until a state of equilibrium, until it reaches the steady state (Table 2 (b)). This steady state can be used to make prediction or different scenarios. Fine modifications of one or several factors in the equilibrium state will yield to different behaviors of the system. Two scenarios were imagined in our model: first, we doubled the Available land (from 0.28 to 0.5, factor 5, Table 3 (c)), second we have increased the Population factor (from 0.5 to 0.7, factor 6, Table 3 (e)).

No	Factors/Concepts (a)	Steady state (b)	Scenario #1 (c)	Steady state for Scenario #1 (d)	Scenario #2 (e)	Steady state for Scenario #2 (f)
1	Secondary facilities	0,45	0,45	0,46	0,45	0,45297123
2	Employment	0,7718162	0,7718162	0,7723359	0,7718162	0,7775885
3	Property cost	0,4713597	0,4713597	0,450166	0,4713597	0,471682
4	Owned housing	0,4957261	0,4957261	0,4999647	0,4957261	0,51165578
5	Available land	0,2867168	0,5	0,5	0,2867168	0,28348341
6	Population	0,5	0,5	0,5	0,7	0,7

7	Rental cost	0,5249792	0,5249792	0,5249792	0,5249792	0,53494295
8	Recreation facilities	0,549834	0,549834	0,549834	0,549834	0,56954622
9	Service facilities	0,477878	0,477878	0,4799941	0,477878	0,4878342
10	Schools	0,598688	0,598688	0,5986877	0,598688	0,63645254

Table 3. The steady state for the FCM in Housing domain and two possible Scenarios

Analyzing the results from the Scenario 1 we can draw the following conclusion:

A change of the value of the Available land variable will have

- medium positive influence on the Secondary facilities, Owned housing and Service facilities
- weak positive influence on the Employment
- strong negative impact on the Property cost

Comparing the scenario with the steady state, we have obtained the following results:

Scenario 1		% of Variables Changed				45,45
Scenario 1 - Steady state		Overall change	Positive Changes	strength (pos)	Negative Changes	strength (neg)
Secondary facilities	0,002101471	medium pos. change	Secondary facilities	medium change	Property cost	strong change
Employment	0,000519718	low pos. change	Employment	weak change		
Property cost	-0,021193707	high neg. change	Owned housing	medium change		
Owned housing	0,004238637	medium pos. change	Service facilities	medium change		
Available land	0,213283241					
Population	0	no change				
Rental cost	0	no change				
Recreation facilities	0	no change				
Service facilities	0,002115606	medium pos. change				
Schools	0	no change				

Table 4. Analysis for Scenario 1

For the second scenario we have reached the following conclusion:

A change of the Population variable will lead to

- strong positive change in Owned housing, Recreation facilities and Schools
- medium positive influence on the Employment, Rental cost and Service facilities
- weak positive influence on the Property cost
- medium negative impact on the Available land
- weak negative impact on the Secondary facilities

Scenario 2	% of Variables Changed					81,82
Scenario 2 - Steady state			Positive Changes	strength (pos)	Negative Changes	strength (neg)
Secondary facilities	- 0,000032	very low neg. change	Employment	medium change	Secondary facilities	very weak change
Employment	0,005772	medium pos. change	Property cost	weak change	Available land	medium change
Property cost	0,000322	low pos. change	Owned housing	strong change		
Owned housing	0,015930	high pos. change	Rental cost	medium change		
Available land	- 0,003233	medium neg. change	Recreation facilities	strong change		
Population	0,200000		Service facilities	medium change		
Rental cost	0,009964	medium pos. change	Schools	strong change		
Recreation facilities	0,019712	high pos. change				
Service facilities	0,009956	medium pos. change				
Schools	0,037765	high pos. change				

Table 5. Analysis for Scenario 2

4. CONCLUSION

Residential location choice is a key determinant of activity-travel behavior and yet, little is known about the underlying reasons why people choose to move, or not move, residences. Such understanding is critical to being able to model residential location choices over time, and design built environments that people find appealing. This approach attempts to fill this gap by developing a FCM that models the decision of moving/not moving of a household and highlight the reason(s) that led to this behavior.

The model described here has identified the main factors that influence the housing decisions and the causal relations between them. Starting from the calculated equilibrium state, two scenarios have been analyzed, so as to see how a minor variation in one variable can influence the other factors and, therefore, the state of the system. These scenarios can be used to make predictions of how the system will react to changes.

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