Soft computing for crisis management and political decision making: the use of genetically evolved fuzzy cognitive maps

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1 January 2005

Soft Computing (2004)
DOI 10.1007/s00500-004-0344-0

ORIGINAL PAPER

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Published online: 10 April 2004

Abstract This paper examines the use of fuzzy cognitive maps (FCMs) as a technique for modeling political and strategic issues situations and supporting the decision-making process in view of an imminent crisis. Its object domain is soft computing using as its basic elements different methods from the areas of fuzzy logic, cognitive maps, neural networks and genetic algorithms. FCMs, more specifically, use notions borrowed from artificial intelligence and combine characteristics of both fuzzy logic and neural networks, in the form of dynamic models that describe a given political setting. The present work proposes the use of the genetically evolved certainty neuron fuzzy cognitive map (GECNFCM) as an extension of certainty neuron fuzzy cognitive maps (CNFCMs) aiming at overcoming the main weaknesses of the latter, namely the recalculation of the weights corresponding to each concept every time a new strategy is adopted. This novel technique combines CNFCMs with genetic algorithms (GAs), the advantage of which lies with their ability to offer the optimal solution without a problem-solving strategy, once the requirements are defined. Using a multiple scenario analysis we demonstrate the value of such a hybrid technique in the context of a model that reflects the political and strategic complexity of the Cyprus issue, as well as the uncertainties involved in it. The issue has been treated on a purely technical level, with distances carefully kept concerning all sides involved in it.

Keywords Neuro-Fuzzy systems · Fuzzy cognitive maps · Hybrid modeling · Genetic algorithms

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1. Introduction

Decision-making and crisis management in a multiple uncertainty environment are important elements in international relations theory [3, 17]. During the decade of the seventies, Axelrod described the cognitive maps using directed, inter connected, bilevel valued graphs applied in politico economic decision theory and policy [3]. In 1986, Kosko extended the graphs of Axelrod to the fuzzy mode thus creating FCMs [11], which were originally proposed as a means of explaining political decision-making processes. Carson and Fuller [5] include a number of reports that describe such cases of FCM implementation modeling specific environments like decision-making and policy-making.

The combination of fuzzy logic and neural networks [1], which has been developed in the world of soft computing [29], creates models that emulate reasoning and the decision-making process using fuzzy causal relationships [13, 11]. The flexibility of such models is improved by allowing for a variety of activation levels for each concept thus creating certainty neuron fuzzy cognitive maps (CNFCM). These have developed to a reliable technique used in strategy selection and evaluation of possibe solutions to intricate political problems [8]. The contribution of genetic algorithms (GAs) to CNFCMs aims at solving the problem of the invariability of the weights and the inability of the method to model a certain political situation following the change of a certain weight or group of weights. In fact, the recalculation of all weights involved in the simulation process constitutes the most important difference between the GECNFCM and the simple CNFCM models.

The paper is organized as follows: Sect. 2 provides the theoretical background on which the model is based, while Sect. 3 briefly describes the formulation and development of a FCM. Sect. 4 presents the CNFCM for the Cyprus issue, as well as the static and dynamic analysis of the model through different scenarios. Sect. 5 introduces the theory of evolutionary computing and genetic algorithms, describing the development of a GECNFCM hybrid model for the Cyprus issue. This section also discusses the experimental results of various simulations conducted through multiple scenario analysis, while the validity of the proposed GECNFCM model is analyzed and discussed in Sect. 6. Finally our conclusions and suggestions for further research on the topic are presented in Sect. 7.

2. Background theory

Soft computing [29, 30] encompasses a range of techniques, namely fuzzy logic, neural network theory, genetic algorithms and probabilistic reasoning [29], generally grouped together to give solutions to specific problems or groups of problems. The technical aspects of the present work are based solely on soft-computing tools, given that soft computing is proposed as a technology in the area of AI, providing the means to contain the information explosion at a level that can be manageable by the human brain.

Zadeh introduced fuzzy logic in 1965 [28] as a means of representing data and manipulating data that was not precise, but rather fuzzy. The theory of fuzzy logic provides a mathematical strength to capture the uncertainties associated with human cognitive processes, such as thinking and reasoning [21, 7]. Since its first appearance, fuzzy logic has been used in a variety of applications, such as image detection of edges, signal estimation, classification and clustering [6]. A fuzzy logic technique represents an alternative solution to the design of intelligent engineering systems. Thus, fuzzy rule-based experts systems are widely applied nowadays, this being supported by the fact that fuzzy logic is linguistic rather than numerical something which makes it similar to human thinking and hence simpler to understand and put in practice.

During the past few years, there has been a large and energetic upswing in research efforts aiming at combining fuzzy logic with neural networks [12]. This combination of neural networks and fuzzy logic seems natural because the two approaches generally view the design of "intelligent" systems from different angles [13]. Neural networks [1, 7] provide algorithms for learning, classification, and optimization [2], whereas fuzzy logic deals with issues such as reasoning on a higher (semantic or linguistic) level. Consequently, the two technologies complement each other. By integrating neural networks with fuzzy logic, it is possible to bring the low-level computational power and learning of neural networks into fuzzy logic systems. The combination of neural networks with fuzzy logic [10] takes place by means of a hybrid system wherein some processing stages are implemented with neural networks and some with a fuzzy inference system [26].

3. Fuzzy cognitive maps

A cognitive map (CM) is a technique based on qualitative reasoning and can be used to cope with knowledge that generally involves many interacting concepts. CM models were introduced by Axelrod [3] in the late 1970's and were mainly used to support political decisions in international relations. Generally, the basic elements of a CM are simple: The concepts used by an individual decision-maker are represented as nodes, and the causal relationships between these concepts are represented as directed arrows. Each arrow is characterized by a weight, a real value that indicates the effect of the causal relationship between nodes. This representation gives a figure of nodes and arrows called a cognitive map in which the various concepts are considered as variables of the system. The advantage of this representation is that it offers a global view of the various links between causal relationships and concepts in the model. Three different types of causal relationships between two nodes p and q ($p \rightarrow q$) are represented in the map indicating the effects as follows:

- Positive (+) causality, in cases in which p promotes, enhances, or is a benefit to q, etc., An increase in the cause variable will bring about an increase in the effect variable; a decrease in the cause concept will result to a decrease in the effect concept.
- Negative (−) causality, in cases in which p retards, prevents, or is harmful to q, etc. In such cases an increase in the cause variable will end up with a decrease of the effect variable and vice-versa.
- No effect (0), when p has no effect on, or does not matter for q, etc.,

The introduction of fuzzy logic contributed to enhancing the potential of the CMs, indicating both the type of representation of the causal relationships between concepts (i.e., positive, negative, zero) and the degree or strength of this relationship.

Fuzzy Cognitive Maps (FCMs) are soft computing tools, which combine elements of fuzzy logic and neural networks. FCM theory was developed recently [11, 12] as an extension of cognitive maps used for planning and decision-making in the fields of international relations, social systems modeling and the study of political developments in the context of such systems. Strictly speaking, a FCM is a figure composed of nodes and edges, the former introducing the qualitative concepts of the analysis while the latter indicate the various causal-relationships. Each concept node possesses a numeric state, which denotes the qualitative measure of its presence in the conceptual domain. Thus, a high numerical value indicates that the concept is strongly present in the analysis while a negative or zero value indicates that the concept is not currently active or relevant to the conceptual domain.

A FCM works in discrete steps [23]. When a strong positive correlation exists between the current state of a concept and that of another concept in a preceding period, we say that the former positively influences the latter, indicated by a positively weighted arrow directed from the causing to the influenced concept. By contrast, when a strong negative correlation exists, it reveals the existence of a negative causal relationship indicated by an arrow charged with a negative weight. Two conceptual nodes without a direct link are, obviously, independent.

The activation level of each of the nodes of the system and the weighted arrows are set to a specific value based on the experts' beliefs. Thereafter, the system is free to interact. This interaction continues until the model:

- Reaches equilibrium at a fixed point, with the activation levels, being decimals in the interval [−1, 1], stabilizing at fixed numerical values.
- Exhibits a limit cycle behaviour, with the activation levels falling in a loop of numerical values under a specific time-period.
- Exhibit a chaotic behaviour, with the activation level reaching a variety of numerical values in a nondeterministic, random way.

In order to increase the reliability of the weight matrix, Kosko suggests consulting more than one expert [22]. Assuming that all experts are consulted with their experience evaluated on a one to ten scale, let S_i be the score of expert i and W_i the weight matrix of the FCM defined by that expert. The final weight matrix is then given by a normalized sum according to the following formula:

$$W = \frac{\sum_{i=1}^{N} S_i W_i}{\sum_{i=1}^{N} S_j} \tag{1}$$

In 1997, the introduction of certainty neuron fuzzy cognitive maps (CNFCMs) [16, 23], provided additional fuzzification to FCMs, by allowing for various activation levels of each concept between the two extreme cases, i.e. activation or not. More specifically, a function $f()$ coming from the area of expert systems [25] was used to return the new certainty factor of a fact after receiving new evidence for, or against previous beliefs based on the present certainty factor.

The updating function of a CNFCM is the following:

$$A_i^{t+1} = f\left(A_i^t, S_i^t\right) - d_i A_i^t \tag{2}$$

where

$$S_i^t = \sum_{\substack{j=1 \\ j \neq 1}}^{n} A_j^t \, w_{ij} \quad , \tag{3}$$

and A_i is the activation level of concept C_i at some time $(t+1)$ or (t).

Equation (3) is the sum of the weighted influences that concept C_i receives at time step t from all other concepts, d_i is a decay factor [15], and

$$f_m\left(A_i^t, S_i^t\right) = \begin{cases} A_i^t + S_i^t(1 - A_i^t) = A_i^t + S_i^t - S_i^t A_i^t, \\ \quad \text{if } A_i^t \geq 0, S_i^t \geq 0 \\ A_i^t + S_i^t(1 + A_i^t) = A_i^t + S_i^t - S_i^t A_i^t, \\ \quad \text{if } A_i^t < 0, S_i^t < 0, |A_i^t|, |S_i^t| \leq 1 \\ (A_i^t + S_i^t)/\left(1 - \min\left(|A_i^t|, |S_i^t|\right)\right), \\ \quad \text{otherwise} \ , \end{cases} \tag{4}$$

is the function used for the aggregation of certainty factors [26]. The meaning of the above function is that the external influence can affect the activation of a concept just to a certain degree. We propose the following modification to the third case of Eq. (4) as follows:

$$\left(A_i^t + S_i^t\right)/\left(1 - \min(A_i^t, S_i^t)\right), \quad \text{otherwise} \tag{5}$$

to cover the undesirable situation in which one of A_i^t and S_i^t equals to 1 and the other to −1 leading the denominator to zero.

Given the structure of a CNFCM as described above, it is easy to see that its ability to combine the input supplied by domain experts, together with its flexibility, makes it a useful tool for analyzing tough political problems and suggesting plausible solutions in an environment of political uncertainty.

4. A FCM model for political decision-making

4.1 The Cyprus issue

Cyprus is the third largest island in the Mediterranean located at its extreme-eastern end. The Republic of Cyprus, which has a population of approximately 750,000 (81.9% Greek Cypriots and 18.1% Turkish Cypriots), gained its independence in 1960. Since 1974, when Turkey launched an invasion "to restore constitutional order" following an abortive coup against the President, Archbishop Makarios, 38% of the island still remains occupied by Turkish forces, which ignore all United Nations resolutions repeatedly expressing their concern on such a major issue. In fact, both in the Security Council and in the General Assembly of the U.N. have been continuously involved in the Cyprus problem since 1964 concerned about the Turkish threat to Cyprus' sovereignty and independence. The U.N. efforts culminated during the recent past with the submission of various versions of the so-called Annan Plan which, however, failed to work out a solution to the Cyprus problem by the end of February 2003. The fact remains, however, that the Republic of Cyprus, making use of extensive support from Greece, is now a full EU member according to the Adhesion Act signed on April 16, 2003, a fact which is hoped to provide the dynamics for the resolution of the Cyprus problem. The eagerness of the Turkish–Cypriot community, however, to profit from the generous EU support to the Cypriot state has been confronted by the threats of the Turkish authorities to annex the occupied part of the island to Turkey in case of its full EU accession. This leaves a lot to be desired concerning the possibilities of co-operation on all sides involved for a settlement of the Cyprus issue. What remains to be seen is the extent to which the new, 25-member EU will be willing to bargain the membership application of Turkey against the settlement of the Cyprus issue and the extent to which the international factor, the US primarily, will be willing to grant its support to the Turkish demands, after its reluctance to back the US invasion against Iraq.

Aiming at relieving the analysis from all traces of emotional bias caused by normative thought, we have decided to resort to technical analysis. What we do, in fact, is employ the theory of fuzzy cognitive maps, which introduces a decision-making tool widely applicable in the area of international relations and politics [17, 18]. This will enable us to forecast developments concerning the Cyprus issue and suggest answers to various complications that may arise in the context of such issues. The next subsection shows how a CNFCM model can be applied to a given political issue by defining the main concepts or variables that affect it and the causal links between them. In this case, we describe the variables involved in the Cyprus issue and their influence upon the main target, namely, the settlement of this problem. Subsects. 4.3 and 4.4 also examine the behaviour of the model using static and dynamic analysis.

4.2 A CNFCM model for the Cyprus issue

The development of our model was based on the method of questionnaires and interviews [20]. The important concepts that influence the Cyprus problem have been identified with the help of a team of domain experts. These experts completed a questionnaire concerning the causal relationships and the weights involved, i.e. the degree to which concepts influence each other, using a positive (+) or negative (−) number between zero and seven, to indicate the direction and intensity of the causal relationships between the concepts. For computational purposes, each number corresponded to the intensity of the casual relationship as follows: absent 1(0.0), very weak 2(0.18), weak 3(0.36), mediocre 4(0.54), strong 5(0.72), very strong 6(0.9) and decisive 7(1.0). The general model was then built (Fig. 1), in which the various concepts of the model interact with one other, while the central concept was the instability/intensity in Cyprus (C1). On the right side of Fig. 1 the weights are presented in a form that indicates the link from the starting to the ending concept, with concepts separated by commas. The sixteen concepts that influence the instability in Cyprus appear in Table 1.

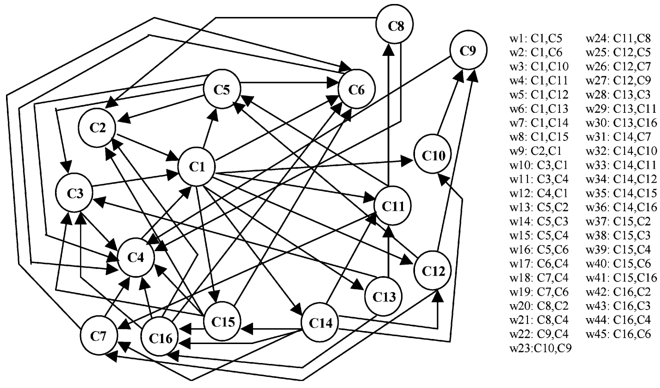

Fig. 1 The Cyprus issue CNFCM model

Table 1 Description of the concepts in the Cyprus issue model

C1	Instability/intensity in Cyprus
C2	Turkish forces actions in Cyprus
C3	Turkish threats
C4	Solution of the Cyprus problem
C5	Greek political support
C6	UN talks on the Cyprus problem
C7	Stability of the Cyprus government
C8	Support to the Turkish forces
C9	Support to the Greek–Cypriot army
C10	Reinforcement of the Greek army
C11	Reinforcement of the Turkish army
C12	Stability of the Greek government
C13	Stability of the Turkish government
C14	EU/NATO economic, military and political support
C15	International influence
C16	Turkish–Cypriot reactions

The opinion of each expert used to define the weights of the different causal links and the initial activation level for each concept, was given a degree of reliability, the latter expressed by a value between one and ten. This value represented the relevance of the expert to the subject and his credibility. Multiplying the degree of reliability of each expert with every weight defined by that expert and then averaging the partial weight matrices, resulted in the final weight matrix (as in Eq. (1)). This is the usual practice followed for obtaining a normalized weight matrix, which can be considered more representative and objective [22]. The weight values of the normalised weight matrix are given in Table 2.

Table 2 Normalized weight matrix

w1	w2	w3	w4	w5	w6	w7	w8	w9	w10	w11	w12
0.10	0.29	0.03	0.32	−0.06	0.10	−0.16	0.13	0.21	0.21	−0.23	−0.21
w13	w14	w15	w16	w17	w18	w19	w20	w21	w22	w23	w24
0.34	0.29	0.06	0.10	0.13	0.23	0.26	0.34	−0.19	0.26	0.23	0.19
w25	w26	w27	w28	w29	w30	w31	w32	w33	w34	w35	w36
0.19	0.06	0.10	0.10	0.16	0.10	0.19	0.13	0.23	0.16	0.16	0.13
w37	w38	w39	w40	w41	w42	w43	w44	w45			
−0.23	−0.19	0.23	0.26	0.19	0.13	0.13	−0.03	−0.03			

4.3 Static analysis

There are two basic types of static analysis: Rule checking and verification. Rule checking ensures that a circuit obeys the restrictions imposed on it by the design environment, while verification ensures that a model obeys the restrictions recommended by the experts so that the intended behaviour complies with the actual one [15, 20].

The static analysis of the model focuses on the characteristics of the weighted arrows presented in the model using graph theory techniques. The most important element to consider is the feedbacks cycles that exist in the graph. Each cycle is accompanied by a sign, which is determined by the multiplication of the signs of the arrows participating in the cycle. If all signs in a cycle are positive or the number of negative signs in the same cycle is even, then the behaviour of the entire cycle is positive. Positive cycles are those that behave as amplifiers [15]. A positive change in the activation of a node in the cycle is leading to a constant increase of the activation at the end of the cycle. The negative cycles on the other hand may neutralize or deactivate the activation at the end of the cycle. This means that the activation level of the ending node will be decreased in cases in which an increase is introduced in the activation of any node in the cycle [26].

The model of Fig. 1 is rich in cycles: 59 cycles exist, 32 of which are positive and 27 negative. The almost equivalent numbers of positive and negative cycles leads to characterizing the model as rather complex. An example of a positive cycle as this appears in Table 3 is $C1+ \rightarrow C11+ \rightarrow C8+ \rightarrow C2+ \rightarrow C1$. This cycle begins with concept C1 (Instability/Intensity in Cyprus). The influence of concept C1 on C11 (the Turkish Forces) is positive, meaning that the instability in Cyprus leads to reinforcing the Turkish army. C11 influences the support to the Turkish forces in Cyprus (C8) positively and this, in its turn, affects the Turkish actions in Cyprus (C2) positively as well. Finally, concept C2 leads to an increase of concept C1 revealing increased instability in Cyprus. It is easy to see that if this cycle persists, then instability in Cyprus will constantly increase.

An example of a negative cycle as this appears in Table 3 is $C1+ \rightarrow C5+ \rightarrow C6+ \rightarrow C4- \rightarrow C1$. The cycle begins with the positive influence of concept C1, initially on the Greek political support (C5) and eventually on the UN talks for the Cyprus problem (C6). This, in its turn, affects the solution of the Cyprus problem (C4) to the same direction, while finally C4 influences the Instability in Cyprus negatively. Therefore, according to this cycle the instability in Cyprus will constantly decrease if a positive change in the activation of any node in the cycle takes place.

If we consider, however, changing the weight w12 from its negative value given by the experts to a positive equivalent, then we must expect a modification in the cycle status of the model as follows: the negative effect of concept C4 (Solution of the Cyprus problem) on concept C1 (instability in Cyprus) expressed by w12 will now be altered to positive, expecting an increase of the intensity and instability in Cyprus as a consequence of a solution to the problem. Indeed, when weight w12 becomes positive, the number of positive cycles is greater than the number of the negative ones (33 positive and 26 negative cycles), meaning that an augmentative tendency exists in our model. The point of this example is that the intensity will not necessarily recede even in cases like this in which the solution of the Cyprus problem encourages it.

A second example of static analysis involves a change of the positive sign of weight w10, which links the concept of the Turkish threats (C3) to that of instability/intensity in Cyprus (C1). A negative w10, involving positive Turkish statements rather than threats (C3) will lead to counting 28 positive and 31 negative cycles. This suggests a receding tendency in the model and a decrease of the intensity in Cyprus, a development that contributes to the solution of the Cyprus issue.

The problem with static analysis, however, is that it involves a large number of restrictions while it is very difficult to identify which of the numerous cycles in a model, 59 in our case, will finally prevail and which are the ones with the strongest effect on the model. In other words, the calculation of the interactions between cycles, the change of the weights each time a new scenario is introduced and the determination of the concept and the weights which will eventually prevail can be very complicated, even for models with a much smaller number of concepts than the one currently studied. These problems can be overcome by the use of dynamic analysis based on computational simulations.

Table 3 Examples of cycles starting and ending at concept C1

C1	w1	+	C5	w13	+	C2	w9	+	C1			
C1	w1	+	C5	w14	+	C3	w10	+	C1			
C1	w2	+	C6	w17	+	C4	w12	−	C1			
C1	w1	+	C5	w15	+	C4	w12	−	C1			
C1	w1	+	C5	w16	+	C6	w17	+	C4	w12	−	C1
C1	w1	+	C5	w14	+	C3	w11	−	C4	w12	−	C1
C1	w3	−	C10	w23	+	C9	w22	+	C4	w12	−	C1
C1	w4	+	C11	w24	+	C8	w21	−	C4	w12	−	C1
C1	w4	+	C11	w24	+	C8	w20	+	C2	w9	+	C1
C1	w5	−	C12	w25	+	C5	w13	+	C2	w9	+	C1
C1	w5	−	C12	w25	+	C5	w14	+	C3	w10	+	C1
C1	w5	−	C12	w26	+	C7	w18	+	C4	w12	−	C1

4.4 Dynamic analysis

The dynamic analysis involves using our model as a technique for strategic management and decision-making in the context of a scenario approach. In broad terms, a scenario is taken to depict some possible political environment in the future, indicating the dynamic sequence of interacting events, conditions and changes that are necessary to reach that state. The scenarios are used for evaluation, selection of strategies, decision-making and identification of future possibilities in face of political uncertainties [4, 21].

Table 4 Activation levels (A_i) calculated by the Cyprus issue CNFCM model

C1	C2	C3	C4	C5	C6	C7	C8
0.69	0.59	0.75	−0.59	0.79	−0.44	−0.74	0.78
C9	C10	C11	C12	C13	C14	C15	C16
−0.65	−0.62	0.60	0.30	0.67	0.56	−0.81	0.54

4.4.1 Model initialization

Our model calculates the new activation levels of the sixteen concepts using Eqs. (2)–(5) converging after 250 iterations (*t* variable in Eqs. (2–5)), when it reaches, in a final immutable situation which can be either an equilibrium, or a limit cycle, or even chaos. Using the weights (w_i) and the activation levels (A_i) as defined by the experts, we left the concepts of the system to interact. The calculated activation levels are presented in Table 4, while Fig. 2 indicates that the model reached an equilibrium state.

4.4.2 The politics of the initial state

After running the CNFCM procedure, the model formed the current political situation of Cyprus as follows: the current activation level of concept C1, which is the instability in Cyprus, was found to be at a high level ($A_1 = 0.69$). This has been influenced by the Turkish actions in Cyprus (C2) with $A_2 = 0.59$, a rather high value explained by the continuous support and upgrade of the Turkish troops in Cyprus by Turkey and the continuous violations of the Greek and Cypriot FIR. The instability is also influenced by the Turkish threats (C3) with $A_3 = 0.75$, a remarkably high figure given the continuing aggressive statements expressed by various Turkish officials as a result of the EU accession of Cyprus without any terms or conditions related to the solution of its political issue.

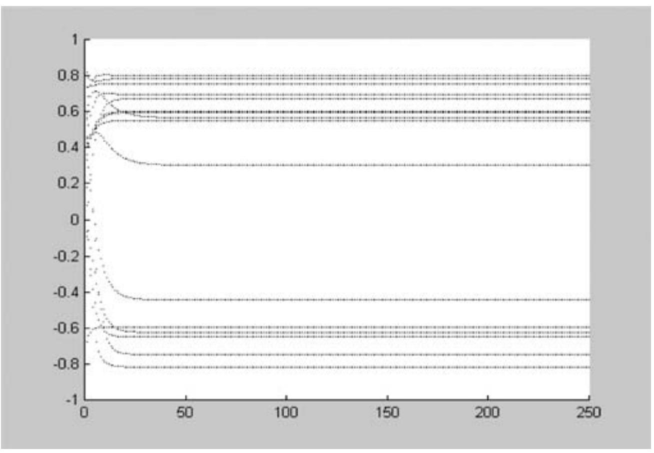

Fig. 2 Stabilization of the CNFCM model in equilibrium

The third concept which affects the instability in Cyprus, is the solution of the Cyprus problem (C4) with $A_4 = -0.59$, a concept inversely related to the intensity in Cyprus, obviously because the Cyprus problem remains unsolved. Concept C15 which is the international influence comes up with an activation level of $A_{15} = -0.81$, indicating that there is a lot of room for pressure on the sides that can contribute to decreasing the intensity in Cyprus. The UN talks on the Cyprus problem represented by C6 bear a negative activation level ($A_6 = -0.44$), given that our recent experience has indicated that the UN alone is not in a position to contribute to the solution of the Cyprus problem effectively. A final concept that appears to exercise an important positive effect is the NATO/EU economic, military and political support represented as C14, with an activation level of $A_{14} = 0.56$

A straightforward conclusion drawn on the basis of these results is that there is a high level of instability in Cyprus, suggesting that the way things are at the present state, a solution to the problem seems to be rather difficult to attain.

4.4.3 Solution of the Cyprus problem: first scenario

This scenario involves differentiating the probability of a solution to the Cyprus problem and changing the weight w12, which is the causal link between concepts C4 and C1, from negative to positive. The value of the weight w12 has been changed from −0.21 to the strongly positive value of 0.7. The meaning of this change is that the solution to the Cyprus problem (C4) is expected to contribute (strongly as the selected value of 0.7 indicates) to the climate of intensity promoting instability in Cyprus (C1). This hypothetical scenario faces a case in which a possible solution may be such that it may not necessarily bring stability and tension reduction.The calculated activation levels reflecting this scenario are given in Table 5 and presented graphically in Fig. 3, indicating that the model reaches equilibrium.

The first conclusion drawn based on this scenario is that there is a considerable chance of a solution to the Cyprus problem, given that the activation level of concept C4 has assumed a substantial positive value ($A_4 = 0.69$). This, however, calls, for a requirement that the Turkish side changes its attitude from aggressive to constructive through a series of positive statements to solve the Cyprus problem. This radical change of atti-

Table 5 Scenario 1: Calculated activation levels (A_i) for w12 = 0.7

C1	C2	C3	C4	C5	C6	C7	C8
0.67	0.58	−0.19	0.69	0.72	0.48	0.77	0.46
C9	C10	C11	C12	C13	C14	C15	C16
0.68	0.63	0.47	0.73	0.48	0.85	0.73	0.42

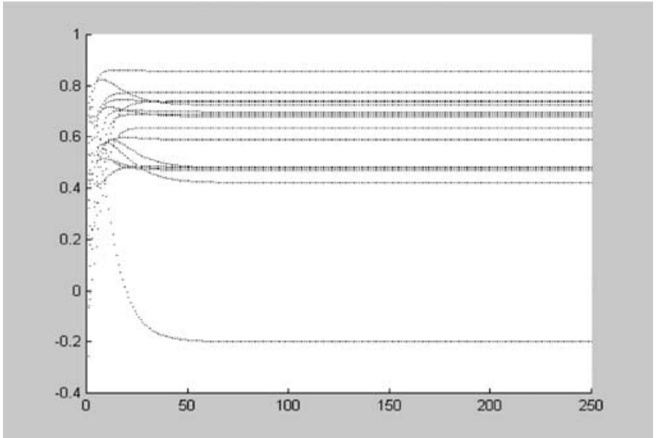

Fig. 3 Scenario 1: equilibrium for w12 = 0.7

tude is reflected in the dramatic decline of the activation level of concept C3 (Turkish threats) down to $A_3 = -0.19$. Moreover, it is interesting to mention that the rise of the activation level of the talks under the UN auspices (C6) to $A_6 = 0.48$ indicates that such talks can be quite helpful and must be continued, together, of course, with the exercise of what we term "International Influence" (C15). The sign of the latter changes and its value becomes strongly positive, indicating its decisive effect upon the possibility of tracing a solution to the Cyprus problem. Likewise, concept C14 representing the political, economic and military support by NATO and the EU, assumes an increased activation level of $A_{14} = 0.85$. This last conclusion points out the possibilities that may be offered by these two powerful entities to a solution to the Cyprus issue. Concerning the government stability in all three countries directly involved in this issue (C7, C12, C13) the corresponding activation levels are considerably high, indicating its essential role in all cases.

A further interesting finding in this scenario concerns the reinforcement of the Greek Army (C10) and the military support to the Greek–Cypriots (C9), the states of which were found weak and inadequate to contribute to the solution of the problem (Table 4). It turns out that this scenario reveals that if the Greek army is strengthened ($A_{10} = 0.63$) and more military support is given to the Greek–Cypriot army ($A_9 = 0.68$), then this may support a solution of the Cyprus issue in the context of a "si vis pacem para bellum" policy (the Latin for "if you want peace prepare for war") [2].

Last, but not least, one must concentrate on a very important conclusion of this experiment: It seems that the unstable environment in Cyprus will continue prevailing given its high activation level ($A_1 = 0.67$), combined with an almost equally high activation level of the Turkish army on the island ($A_2 = 0.58$). This simply means that a solution to the Cyprus issue will not necessarily lead to stability, the latter being adversely affected by the strong presence of the Turkish troops on the island.

4.4.4 Solution of the Cyprus problem: second scenario

To face the adverse repercussions predicted by the first scenario we have resorted to asking the model to forecast the political impact in cases in which the activity of all Turkish forces is neutralized. Thus, after setting the weight w9, which represents the causal link between concepts C2 and C1, to zero the model has reached a mixed state of equilibrium and limit cycles as depicted in Fig. 4.

It is impressive to notice in Table 6 that the relevant activation level has turned to negative ($A_1 = -0.11$), meaning that there are chances for attaining a stable equilibrium in Cyprus after all! However, combining the concept solution of the Cyprus problem (C4) with an activation level of $A_4 = 0.07$, leads to a neutral environment, implying that in this scenario the Cyprus issue seems to simmer down to an environment of inertia. This may be due to the absence of events causing a general instability that could trigger reactions from the part of the public opinion and give the necessary momentum to the settlement of the problem. This leads to a conclusion very much similar to that of the previous scenario, i.e., that the solution of the Cyprus problem may not, under the circumstances, contribute to bringing about stability in Cyprus. Regarding the international influence (C15), this assumes a lower activation level compared to the first scenario ($A_{15} = 0.34$) revealing the reluctance of the international factor to become involved with an issue that does not emerge as a source of intensity in the broader geographical area. Generally speaking, the main conclusion of this scenario refers to the tendency of most concepts to be neutralised given the absence of actions of the Turkish troops in Cyprus.

4.4.5 Solution of the Cyprus Problem: third scenario

This scenario involves further reduction of weight w9 that links C2 (Turkish forces actions in Cyprus) with C1 (instability in Cyprus) down to −0.6. The political meaning of this change is that the actions on behalf of

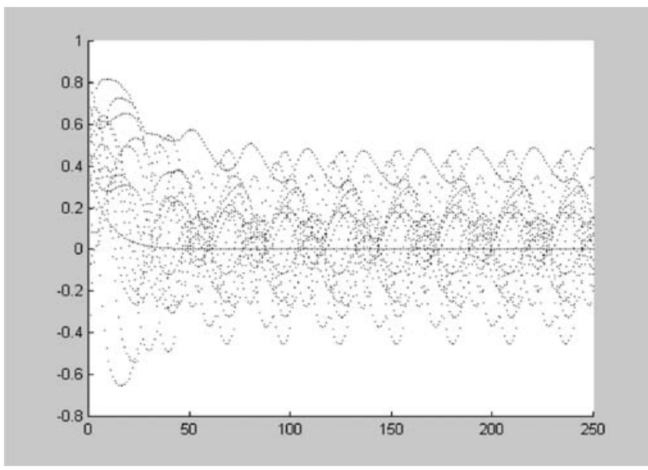

Fig. 4 Scenario 2: limit cycle and equilibrium for w9 = 0.0

Table 6 Scenario 2: final activation levels (A_i) for w9 = 0

C1	C2	C3	C4	C5	C6	C7	C8
−0.11	0.00	0.17	0.07	−0.19	0.06	0.15	−0.09
C9	C10	C11	C12	C13	C14	C15	C16
0.15	0.07	0.02	0.14	0.12	0.48	0.34	−0.05

the Turkish troops in Cyprus can reduce instability on the island, possibly due to a withdrawal of the Turkish forces from Cyprus. As a result the model has reached a chaotic behaviour, as depicted in Fig. 5. These results, however, cannot be discussed due to the absence of reliable (stable) results.

5. The GECNFCM hybrid model

5.1 Evolutionary programs and genetic algorithms

Genetic algorithms are a part of evolutionary computing [9, 16], which is a rapidly growing area of Artificial Intelligence. The structure of an evolution program in pseudocode form is shown in Fig. 7. The evolution program is a probabilistic algorithm, which maintains a population of individuals (also called chromosomes) $P_t = (x_1, x_2, \ldots x_n)$ for each generation (iteration) t. Each individual x_i represents a potential solution to the problem at hand and it is evaluated using some measure of its ''fitness''. Then, the new population (iteration) $(t+1)$ is formed by selecting the individuals bearing the highest fit (select step). Some members of the new population undergo transformations (alter step) by means of ''genetic'' operators to form new solutions via unary transformations m_i (mutation type). These create new individuals by a small change in a single individual and higher order transformations c_j (crossover type) which, in their turn, create new individuals by combining parts from several (two or more) individuals. After some number of generations the program converges, while the best individual is considered as representing a near-optimum (reasonable) solution.

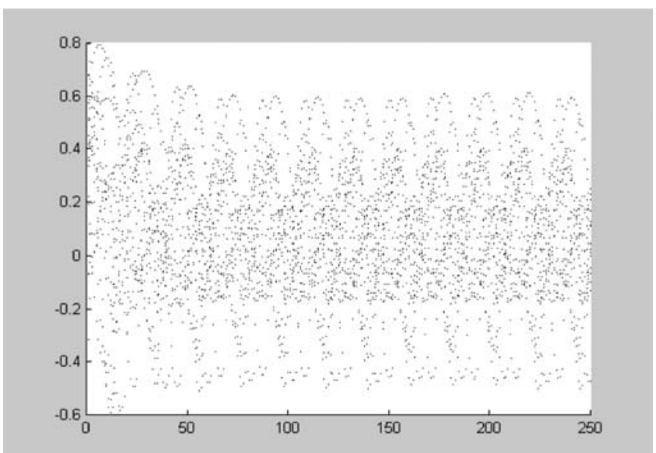

Fig. 5 Scenario 3: chaotic behaviour for w9 = −0.6

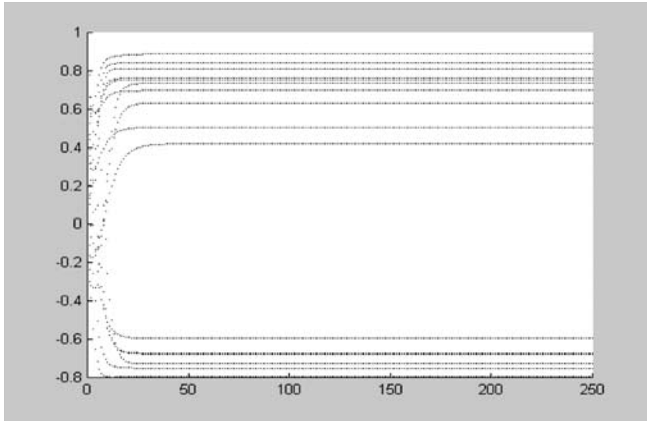

Fig. 6 Equilibrium for target $A_1 = 0.95$

Genetic algorithms (GA) are domain independent, thus they can be useful in many applications. It is not surprising, therefore, that evolution programs, incorporating problem-specific knowledge in the chromosomes data structure and specific ''genetic'' operators, perform much better. Classical genetic algorithms, which operate on binary string encoding for the individuals require a modification of the original problem to an appropriate binary form for the GA [9]. This would include mapping between potential solutions and binary representation, taking care of decoders or repair algorithms. On the other hand, evolutionary programs would leave the problem unchanged, modifying a chromosome representation of a potential solution using ''natural'' data structures and applying appropriate ''genetic'' operators.

A GA essentially provides a search procedure, which optimises an objective function $\varphi()$ by maintaining and evolving a population P of candidate solutions. The population is evolved through the crossover and mutation operations mentioned earlier which are employed to generate new individuals. The computation procedure of the GA starts with random initialisation of the individuals forming the first generation of the population. The objective function is then evaluated for every individual

```
Procedure evolution program
  begin t ← 0 ;
    Initialize P(t) ;
    Evaluate P(t) ;
    while not (termination condition) do
      begin
        t ← t+1 ;
        select P(t) from P(t-1) ;
        alter P(t) ;
        evaluate P(t)
      end
  end
```

Fig. 7 The evolution procedure in pseudo-code and depending on the fitness of each of these individuals some members are selected for the next generation. These undergo mutation and/or crossover transformations according to some probability and the fitness function is applied on the members of the new generation. The GA procedure is then repeated for a certain number of iterations called epochs or generations. The algorithm terminates if a predefined condition is met or if a maximum number of epochs is reached. The individual yielding the best fitness value throughout all generations gives the optimal solution.

The essence of the genetically evolved certainty neuron fuzzy cognitive map (GECNFCM) model proposed in this paper lies with tracing the optimal weight matrix corresponding to a desired activation level for a given concept as computed by a simple CNFCM model. More specifically, the GA evolves a population of individuals each of which consists of a weight matrix describing the degree of causal relationships between the concepts of Fig. 1. The initial generation contains weights matrices with random values. The evolution of the individuals is performed with the help of the CNFCM model, which computes the final activation levels of the concepts using Eqs. (1) and (2). The activation level of a certain concept in focus denoted by A_i is used to calculate the fitness of each individual-weight matrix WM_i according to the following function:

$$\text{fitness } (WM_i) = 1/(1 - \text{abs}(A_{d,i} - \text{mean}_{50}(A_{a,i})) \qquad (6)$$

where $A_{d,i}$ is the target (desired) value of the activation level for the concept in focus C_i and mean_{50} $(A_{a,i})$ is the mean value of the last fifty actual activation levels of concept C_i as these are computed by the CNFCM (t variable in Eqs. (2) to (4)). It is clear from Eq. (6) that the closer to the target value this mean value is, the more appropriate the weight matrix. In fact, the fitness function uses the average of the last fifty activation levels to take into consideration a possible final state of the model which presents limit-cycles, that is, a state in which the $A_{d,i}$ exhibit periodic fluctuations and do not stabilize at equilibrium values. Thus, if the activation level of the concept in focus reaches equilibrium then the corresponding weight matrix in this case can be considered more appropriate compared to another individual-matrix that has resulted to limit cycles or chaos.

All simulations conducted in the next section have been based on the following constant values for the variables involved: The population size has been set equal to 100 and the number of generations equal to 400. The weight values were initialized in the range [−1, 1] while the probability of applying the genetic operator of crossover was set to 0.25 and that of mutation to 0.01.

5.2 Experimental results

Simulations were performed as follows: the first step involved studying the activation levels calculated by the CNFCM model (Table 4) at equilibrium using the initial weight matrix shown in Table 2. The next step was to simulate different scenarios by asking the model to reach a desirable activation level for a certain concept that the policy-maker focuses on. The GECNFCM model calculated the new optimal weight matrix, which was then used by the CNFCM model to recalculate the new activation levels of the 16 concepts.

More specifically, let us assume that we are interested in concept C_i. The series of steps to simulate a hypothetical scenario are as follows:

Step 1: Calculate the activation levels (*AL*s) of the 16 concepts at equilibrium using the CNFCM model of Fig. 1 and the weight matrix of Table 2.

Step 2: Study the level of activation of C_i and set up a hypothetical scenario for simulation purposes where the activation level of C_i will be higher or lower than the computed value.

Step 3: Set the desired level of activation for C_i (denoted by $AL_{i,target}$) and invoke the Genetic Algorithm in the GECNFCM model.

Step 4 (GECNFCM model internal tasks): Start with an initial population each individual of which is a weight matrix with randomly selected values. Using each individual-weight matrix, calculate the *AL*s of the 16 concepts. Compare the computed activation level of C_i with the targeted value $AL_{i,target}$. Calculate the fitness of each individual-weight matrix according to Eq. 6. Select the best fitted individuals for evolution (crossover and mutation), thus altering the weight values in each selected individual. Repeat the process until the target value $AL_{i,target}$ is met by a certain weight matrix evolved by the GA part, or until a certain number of iterations is reached.

Step 5: If the target is met, then feed the optimal weight matrix evolved by the GECNFCM to the simple CNFCM and calculate the *AL*s once again. Study the activation level values calculated in order to assess the contribution of the 15 concepts (excluding the target concept) to the formation of the specific case-study scenario (i.e., reaching the desired activation level of C_i).

The recalculation of all weights that participate in the simulation process constitutes the most important difference between the GECNFCM and the simple CNFCM models. Its importance to the decision-makers is underlined by the fact that they will be able to introduce hypothetical cases based on a target activation level set for a certain concept in the model.

5.2.1 Scenario 1: an environment of increased instability

What the model does in this scenario is to calculate the new weight matrix in case in which instability in Cyprus rises. This possibility is introduced in the model by increasing A1 from 0.69 to 0.95. Using the optimal weights calculated by the GECNFCM indicated in

Table 7 Increased instability ($A_1 = 0.95$): GECNFCM optimal weight matrix

w1	w2	w3	w4	w5	w6	w7	w8	w9	w10	w11	w12
0.89	0.90	0.98	−0.03	−0.19	−0.21	0.02	−0.15	−0.75	−0.53	0.18	0.81
w13	w14	w15	w16	w17	w18	w19	w20	w21	w22	w23	w24
0.05	−0.33	0.91	0.42	0.89	0.39	0.28	0.73	0.11	−0.59	−0.24	0.88
w25	w26	w27	w28	w29	w30	w31	w32	w33	w34	w35	w36
−0.76	−0.68	−0.37	−0.28	−0.40	0.32	−0.78	0.07	−0.84	−0.78	−0.69	0.35
w37	w38	w39	w40	w41	w42	w43	w44	w45			
−0.52	−0.49	0.71	−0.01	−0.50	−0.02	0.07	0.34	−0.004			

Table 8 Increased instability ($A_1 = 0.95$): activation levels calculated with GECNFCM's optimal weights

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
0.88	−0.75	−0.59	0.76	0.84	0.75	0.69	−0.67	−0.67	0.41	−0.72	−0.79	0.73	0.63	0.81	0.50

Table 7 the final activation levels of Table 8 were obtained. As depicted in Fig. 6, the model has reached equilibrium. The cause of the increased instability in Cyprus ($A_1 = 0.88$) has been traced as the combined result of an increase of concepts' C2 and C3 influence. These concepts represent the Turkish provocative actions ($w9 = -0.75$; $A_2 = -0.75$) and the Turkish threats ($w10 = -0.53$; $A_3 = -0.59$) respectively. The unstable environment is further aggravated given the combination of the negative activation levels of C2 and C3 to the weights that link them with C1 which have turned from positive (Table 2), to negative (Table 7). The activation level of 0.76 which concept C4 (solution of the Cyprus problem) has assumed can only contribute to this instability.

A further interesting point regards the consequences of a reduction to the support offered to the Turkish forces on the island, a possibility which is introduced by reducing the appropriate activation level down to $A_8 = -0.67$ from $A_8 = 0.78$ and results to a reduction of the provocative statements, threats and actions from the part of Turkey. In addition, the effectiveness of reducing the support to the Turkish forces is revealed by the increase of the corresponding weight (w20) to twice its original value due to the reduction of the Turkish forces, as indicated by the relevant weights and activation levels. Concluding the experiments describing an environment of instability we have noticed that the pronounced activation level of the international influence (C15) turned from negative to positive, while its impact upon solving the Cyprus problem (w39) rose to three times as much compared to its baseline value, underlining the importance of the pressure exercised by international organizations or superpowers.

5.2.2 Scenario 2: Solving the Cyprus problem

This scenario examines the solution of the Cyprus problem in two ways: the first involves simulating a situation according to which the potential of a solution to the problem is decreased, while the second considers the case in which this potential is increased. In the former case the simulations were performed with a targeted activation level $A_4 = -0.9$, while in the latter case this level rose to $A_4 = -0.2$.

Decreasing the activation level of C4 to −0.9 the GECNFCM yields the optimal weight matrix depicted in Table 9, which activates the concept almost to its equilibrium target value ($A_4 = -0.86$; Table 10, Fig. 8). The concept interaction in this case is the following: Intensity in Cyprus climbs to $A_1 = 0.93$, while the Turkish actions decrease to $A_2 = -0.84$ and the Turkish threats are almost neutralized. This high level of intensity comes as a result of the negative A_2 together with the negative w9 linking C2 with C1 (Table 9), the multiplication of which contributes positively to increasing A_1. The same holds for A_4 and w12, linking C4 with C1, while the international influence (C15) is negatively activated ($A_{15} = -0.83$), thus affecting the solution to the Cyprus problem adversely given its positive link to C4. The Turkish government appears quite unstable ($A_{13} = -0.75$), while the strengthening of the Turkish army is highly activated ($A_{11} = 0.73$). These are certainly

Table 9 Solving the Cyprus problem: GECNFCM optimal weight matrix for targeted $A_4 = -0.9$

w1	w2	w3	w4	w5	w6	w7	w8	w9	w10	w11	w12
0.43	−0.85	−0.98	0.98	−0.04	−0.82	0.63	−0.98	−0.81	−0.61	−0.70	−0.93
w13	w14	w15	w16	w17	w18	w19	w20	w21	w22	w23	w24
−0.23	−0.94	−0.44	−0.90	0.76	−0.79	−0.73	0.33	0.55	0.30	−0.81	−0.43
w25	w26	w27	w28	w29	w30	w31	w32	w33	w34	w35	w36
0.57	−0.41	−0.58	−0.28	0.55	0.90	−0.40	0.39	−0.64	−0.96	−0.20	−0.76
w37	w38	w39	w40	w41	w42	w43	w44	w45			
−0.09	−0.21	0.81	0.63	0.20	0.99	−0.76	0.01	−0.22			

Table 10 Solving the Cyprus problem: GECNFCM activation levels for targeted $A_4 = -0.9$

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
0.93	−0.84	0.18	−0.86	0.89	−0.83	0.90	−0.84	−0.66	0.79	0.73	0.79	−0.75	−0.77	−0.83	−0.85

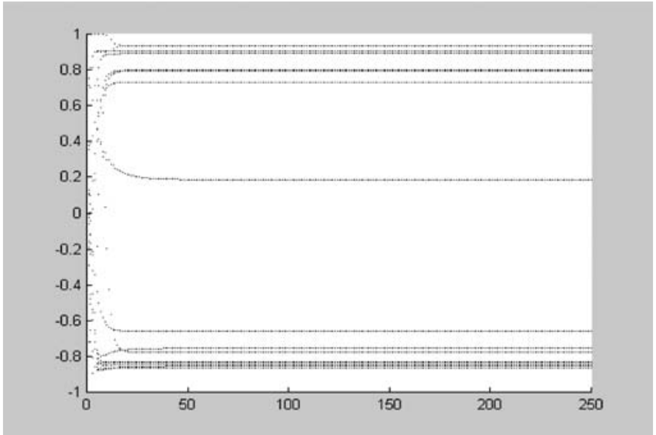

Fig. 8 Equilibrium for target $A_4 = -0.9$

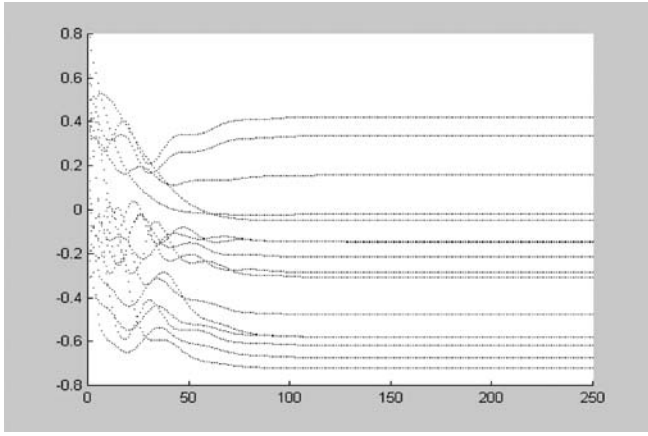

Fig. 9 Equilibrium for target $A_4 = -0.2$

expected to contribute to raising tension in the area, given the tendency of the Turkish authorities to "export" their domestic economic, political and social problems in a crisis form.

Turning to our second alternative to attain a solution to the Cyprus problem, setting the target $A_4 = -0.2$ seems to be more fruitful as the equilibrium values of the results indicate (Tables 11 and 12, Fig. 9). While A_4 rises to −0.21, intensity appears to be significantly decreased to the value of $A_1 = -0.14$, unlike the previous case, given the drop of both the level of the Turkish forces actions in Cyprus and that of the Turkish threats. A comparison of these results to those calculated by the CNFCM (Table 4) shows that the level of the negotiations for a solution is reactivated (i.e., the corresponding concept level of C6 turns from negative to positive), while the support to the Turkish forces on the island is neutralized.

5.2.3 Scenario 3: increase and decrease of the Turkish threats

This case involves a hypothetical situation in which the Turkish threats increase and decrease (both in terms of intensity and number of cases) in an attempt to examine the corresponding impact on intensity and, subsequently, on the possibility of a solution to the Cyprus problem. Simulations were performed with a targeted activation level $A_3 = 0.9$ for increased and $A_3 = -0.5$ for decreased.

Increasing the activation level of C3 yields the optimal weight matrix presented in Table 13, which activates the sixteen concepts as shown in Table 14 and Fig. 10. Here we can see that the rise of the Turkish threats causes an increase in the intensity in Cyprus and the Turkish forces actions $(A_1 = 0.86, A_2 = 0.84)$ as one might have expected. In addition, the potential of a solution to the Cyprus problem is quite high $(A_4 = 0.81)$, possibly due to the fact that when tension is observed in a certain geographical area then the international community focuses on smoothening it out. It is also worth noticing that stability in the three governments is low $(A_7 = 0.13, A_{12} = -0.51, A_{13} = -0.10)$, something which may actually be the cause of the increase of the Turkish threats (i.e., the Turkish authorities, both political and military, may be counting on emphasizing on the Cyprus problem to increase their popularity).

Table 11 Solving the Cyprus problem: GECNFCM weight matrix for targeted $A_4 = -0.2$

w1	w2	w3	w4	w5	w6	w7	w8	w9	w10	w11	w12
−0.81	0.27	0.76	0.27	−0.86	0.15	−0.09	0.96	0.75	−0.57	0.95	0.52
w13	w14	w15	w16	w17	w18	w19	w20	w21	w22	w23	w24
0.58	−0.15	0.41	−0.70	−0.64	−0.60	−0.52	0.33	−0.40	−0.93	−0.89	0.62
w25	w26	w27	w28	w29	w30	w31	w32	w33	w34	w35	w36
−0.10	−0.12	−0.79	0.69	0.53	−0.91	0.55	0.57	0.25	0.02	0.65	0.68
w37	w38	w39	w40	w41	w42	w43	w44	w45			
0.01	0.45	0.57	−0.62	−0.60	−0.12	−0.01	0.52	0.37			

Table 12 Solving the Cyprus problem: GECNFCM final activation levels for targeted $A_4 = -0.2$

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
−0.14	−0.28	−0.30	−0.21	−0.61	0.33	−0.14	−0.02	0.42	−0.57	−0.04	−0.47	−0.58	−0.72	−0.27	0.15

Table 13 Rise of Turkish threats: GECNFCM optimal weight matrix for targeted $A_3 = 0.9$

W1	w2	w3	w4	w5	w6	w7	w8	w9	w10	w11	w12
−0.05	0.84	0.75	−0.78	0.31	−0.69	0.86	0.02	0.78	0.39	0.64	0.63
W13	w14	w15	w16	w17	w18	w19	w20	w21	w22	w23	w24
−0.23	−0.32	0.26	0.49	0.31	−0.40	0.52	0.45	0.02	−0.22	−0.12	−0.88
w25	w26	w27	w28	w29	w30	w31	w32	w33	w34	w35	w36
−0.27	−0.15	0.03	−0.84	−0.85	0.01	−0.74	−0.42	−0.83	0.37	0.40	0.61
w37	w38	w39	w40	w41	w42	w43	w44	w45			
−0.69	0.52	0.68	0.22	0.35	−0.16	−1.00	−0.54	−0.47			

Table 14 Rise of Turkish threats: GECNFCM activation levels for targeted $A_3 = 0.9$

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
0.86	0.84	0.87	0.81	0.34	0.67	0.13	0.76	−0.59	0.36	−0.84	−0.51	−0.10	−0.71	0.68	−0.85

Decreasing the activation level of C3 yields the optimal weight matrix presented in Table 15, which activates the sixteen concepts as shown in Table 16 and Fig. 11. The reduction of Turkish threats doesn't reduce the intensity in Cyprus, which remains high ($A_1 = 0.79$). This is due to the fact that the possibility of a solution to the Cyprus problem remains too low ($A_4 = -0.7$, $w12 = -0.5$). In addition, weight w11, that is, the causal link between C3 (Turkish threats) and C4 (solution of the Cyprus problem), is 0.82, while in the initial case it was 0.12, indicating the strong influence of this concept (C3) to the solution of the Cyprus problem. Concept C15 is a vital concept and its positive value $A_{15} = 0.66$ shows the important international influence on the reduction of Turkish threats.

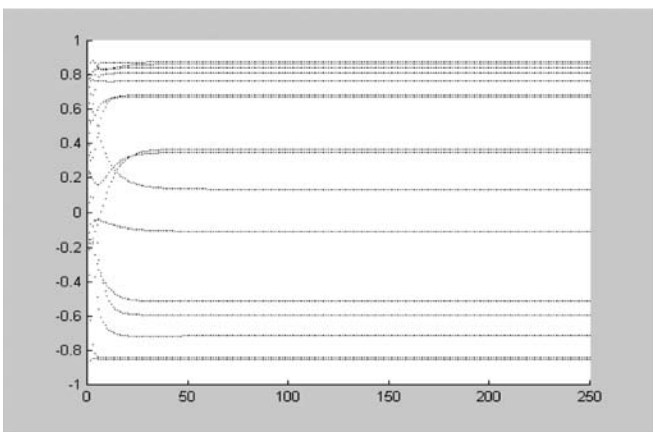

Fig. 10 Equilibrium for target $A_3 = 0.9$

5.2.4 Scenario 4: increase and decrease of international influence

This is a scenario that examines the international influence on the solution of the Cyprus problem in two ways: the first involves simulating the situation under which the international interest of a solution to the problem is decreased, while the second investigates the possibility this interest is slightly increased. In the former case the simulations were performed with a targeted activation level $A_{15} = -1$, while in the latter case this level was $A_{15} = -0.4$.

Decreasing the activation level of C15 yields the optimal weight matrix presented in Table 17, which activates the sixteen concepts as shown in Table 18 and Fig. 12. Decreasing the international influence shows that the instability in Cyprus rises ($A_1 = 0.88$) and the Turkish threats in the absence of international interest increase considerably ($A_3 = 0.85$, $w1 = 1$). The possibility of the solution to the Cyprus problem decreases $A_4 = -0.74$ and there are no talks for its solution $A6 = -0.58$. The reduction of the international influence affects the strength of the Greek army negatively ($A_{10} = -0.83$) and the strength of Turkish army positively ($A_{11} = 0.81$). The Turkish–Cypriots do not seem to approve of the international involvement for the solution to the Cyprus problem ($A_{16} = 0.73$).

The absence of influence of the international factor, in addition, results in stabilizing the governments of Cyprus ($A_7 = 0.8$), Turkey ($A_{13} = 0.51$) and Greece ($A_{12} = 0.86$), indicating that a strong presence of the international factor creates instability in the governments of the three countries which are directly involved in the Cyprus issue.

Table 15 Reduction of Turkish threats: GECNFCM optimal weight matrix for targeted $A_3 = -0.5$

w1	w2	w3	w4	w5	w6	w7	w8	w9	w10	w11	w12
0.95	−0.74	0.88	0.05	0.95	0.41	−0.44	−0.29	−0.35	0.65	0.83	−0.52
w13	w14	w15	w16	w17	w18	w19	w20	w21	w22	w23	w24
−0.54	−0.86	−0.67	0.75	−0.13	−0.03	−0.42	−0.31	−0.53	−0.18	0.45	0.38
W25	w26	w27	w28	w29	w30	w31	w32	w33	w34	w35	w36
−0.76	−0.45	0.23	−0.37	0.48	0.34	−0.58	0.16	−0.69	−0.80	−0.60	0.71
w37	w38	w39	w40	w41	w42	w43	w44	w45			
0.15	−0.56	−0.68	0.03	0.55	−0.08	0.25	−0.14	−0.54			

Table 16 Reduction of Turkish threats: GECNFCM activation levels for targeted $A_3 = -0.5$

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
0.79	−0.61	−0.26	−0.70	0.87	0.34	−0.39	0.76	0.42	0.51	0.61	−0.68	0.60	−0.50	0.66	0.35

In the second case, we used the model to simulate future developments in cases in which the international influence is increased, applying a certain amount of pressure towards solving the Cyprus problem. Increasing the activation level of C15 yields the optimal weight matrix presented in Table 19, which activates the sixteen concepts as shown in Table 20 and Fig. 13. This pressure has a direct impact on the reduction of the Turkish actions ($A_2 = -0.52$) and Turkish threats (C3) from $A_3 = 0.72$ to $A_3 = 0.42$. As a consequence, the possibility of solving the Cyprus problem is increased. The UN talks on this issue assume an activation level of almost zero ($A_6 = 0.07$), indicating that when the international influence is highly activated the UN talks may come second best and that alternative ways for achieving a solution to the problem may be used (e.g., USA or EU initiatives).

5.2.5 Scenario 5: reduction of support to the Turkish forces in Cyprus

This is a highly unrealistic scenario in which the model calculates the new weight matrix for the hypothetical case in which the Turkish government reduces the support to the Turkish forces in Cyprus. This possibility is introduced in the model by decreasing the activation level A_8 from 0.78 to −0.2. The optimal weight matrix is presented in Table 21, which activates the sixteen concepts as shown in Table 22. Fig. 14 shows that the model exhibits a limit cycle behaviour, indicating a weak point of the method that recommends the careful interpretation of the results.

Reduction of military support to the Turkish forces in Cyprus has a minor negative impact on the concept representing the Turkish forces actions in Cyprus (C2) with its activation level reducing to $A_2 = 0.17$. Turkish threats (C3) remain almost at the same level ($A_3 = 0.61$ from 0.75). A further interesting point to be discussed is the reduction of the reinforcements to the Turkish army (C11) to the value of $A_{11} = 0.3$. This reduction can only occur in the absence of NATO and EU political, economic and military support ($A_{14} = -0.89$).

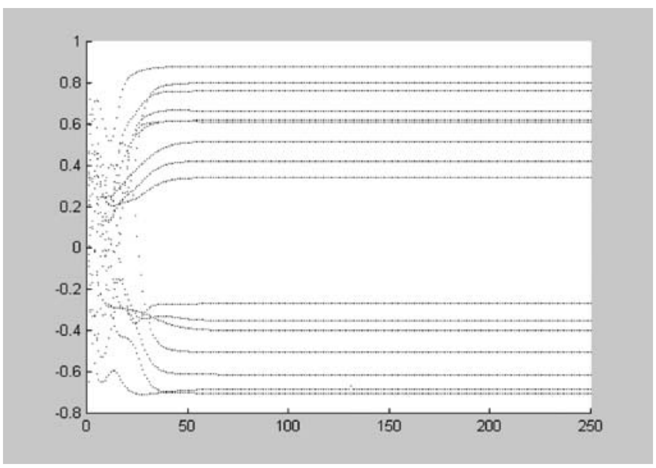

Fig. 11 Equilibrium for target $A_3 = -0.5$

6. Validation of the hybrid model on a real case: the S-300 crisis

Unlike the hypothetical cases examined thus far, the hybrid model is tested in an environment of an actual incident, aiming at measuring its ability to face actual crises. What we do, more specifically, is to consider the so-called S-300 crisis [27], namely the issue that had been going on between January 1997 and December 1998, involving Cyprus, Greece and Turkey. It is briefly reminded that the installation of such an efficient long-range ground to air missile on Cyprus was considered a threat against Turkey, improving the effectiveness of the Greek and Cypriot armed forces in the context of the Integrated Defense Doctrine, while, in parallel, compelling Turkey to resort to purchasing expensive countermeasures to such an alleged threat. The Greek side, in its turn, claimed that the installation of the S-300 would not be enough to disturb the balance of power in the area, given that these missiles would be exposed to a sudden blow from the part of Turkey to which they

Table 17 Reduction of international influence: GECNFCM optimal weight matrix for targeted $A_{15} = -1$

W1	w2	w3	w4	w5	w6	w7	w8	w9	w10	w11	w12
0.61	0.13	−0.45	0.45	−0.10	−0.13	−0.23	−0.83	−0.45	1.00	0.20	−0.39
w13	w14	w15	w16	w17	w18	w19	w20	w21	w22	w23	w24
0.67	−0.13	0.63	−0.97	0.22	−0.40	−0.31	0.43	−0.75	0.92	0.71	0.82
w25	w26	w27	w28	w29	w30	w31	w32	w33	w34	w35	w36
−0.30	0.44	−0.20	0.65	0.30	−0.93	0.89	0.20	−0.05	−0.62	−0.84	0.01
w37	w38	w39	w40	w41	w42	w43	w44	w45			
0.56	−0.85	0.49	−0.08	0.69	−0.84	−0.81	0.15	−0.84			

Table 18 Reduction of international influence: GECNFCM activation levels for targeted $A_{15} = -1$

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
0.88	−0.76	0.85	−0.74	−0.81	−0.58	0.80	0.65	−0.85	−0.83	0.81	0.86	0.51	−0.79	−0.89	0.73

would be able to respond only if they survived. In such a case, therefore, any form of destabilizing action in the area would only come from the Turkish side, given that the role of the S-300 would have been purely defensive. The strong opposition to this purchase by the USA and Great Britain finally led to the installation of the missiles in the island of Crete and to the purchase of just a short-range ground to air system for Cyprus instead.

In order to analyze the environment described above, we first simulated the S-300 incident using the CNFCM model of Fig. 1 and the weight matrix presented in Table 23. The final activation levels of the sixteen concepts involved are listed in Table 24 and depicted graphically in Fig. 15 reflecting a picture characterized by increased tension ($A_1 = 0.79$) and strong reactions and threats from the part of Turkey ($A_2 = 0.87$ and $A_3 = 0.77$ respectively). It is reminded that these threats included attacking and destroying the system once installed and were accompanied by sending F16 air fighters to the occupied airport of Lefkoniko aiming at reinforcing the Turkish position on the island [27]. In short, the results obtained reproduce the atmosphere prevailing on the island during the actual crisis period, when the FIR violations, the support to the Turkish forces on the island and the intense diplomatic activity from the part of Turkey were culminating. These seem to lead to adverse repercussions as regards possibilities of a solution to the Cyprus problem ($A_4 = -0.77$) and chances for peace talks ($A_6 = -0.63$), while both the Cypriot and the Turkish governments suffer destabilizing effects ($A_7 = -0.41$ and $A_{13} = -0.71$ respectively), results which are strongly supported by historical evidence referring to the period under study [27]. The incident, however, does not appear to affect the stability of the Greek government ($A_{12} = 0.60$), the support of which to the Greek–Cypriot army appears to be considerable ($A_9 = 0.70$), as it has been the case. The support to the Turkish forces on the island is very strong ($A_8 = 0.88$), a development sustained by the strength of the Turkish forces ($A_{11} = 0.66$). Finally, the international influence has affected the crisis ($A_{15} = -0.85$) negatively, given that, at least indirectly, it encouraged Turkish aggressiveness by opposing the purchase of the S-300 system.

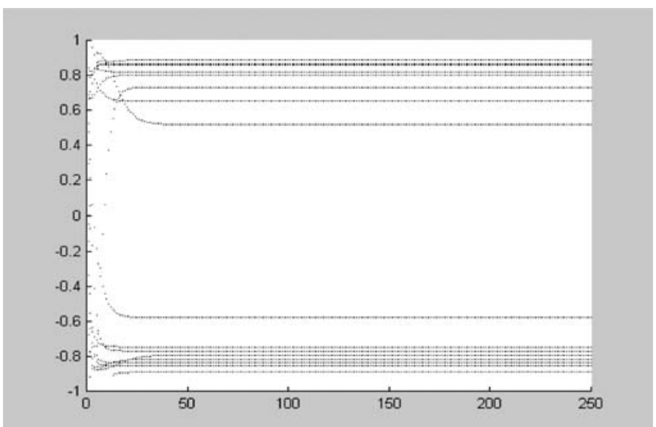

Fig. 12 Equilibrium for target $A_{15} = -1$

At this stage we requested the model to consider a 50% reduction of the intensity on the island, aiming at evaluating the extent to which it can reflect the climate prevailing on the island with the tension cooling down after December 1998. The model has indeed reached the intensity-reduction target by attaining equilibrium at $A_1 = 0.37$ (Table 26 and Fig. 15). The role of the international influence, once it took initiatives, climbed from $A_{15} = -0.85$ to $A_{15} = 0.74$ indicating reluctance to approve of the Turkish threats and actions in Cyprus that used to support a climate of tension, while its pressure on the Cypriot side contributed to the same direction considerably. The latter is introduced in the model through the weight w40 = 0.27 (Table 25) which links the international influence C15, to the peace talks C6. The negative weight w39 = −0.50 that links C15 with C4 (solution to the Cyprus issue), implies a decrease of the international support to the solution of the problem, something which reflects the shift of emphasis

Table 19 Increase of international influence: GECNFCM optimal weight matrix for targeted $A_{15} = -0.4$

w1	w2	w3	w4	w5	w6	w7	w8	w9	w10	w11	w12
0.22	0.95	0.27	0.94	0.73	−0.86	−0.15	−0.04	0.66	−0.52	0.09	0.25
w13	w14	w15	w16	w17	w18	w19	w20	w21	w22	w23	w24
−0.90	0.44	−0.24	0.91	−0.15	−0.21	0.05	0.15	−0.36	0.11	−0.40	−0.43
w25	w26	w27	w28	w29	w30	w31	w32	w33	w34	w35	w36
0.47	0.75	0.17	0.56	−0.30	0.84	0.39	0.33	0.01	0.05	−0.23	−0.42
w37	w38	w39	w40	w41	w42	w43	w44	w45			
−0.36	−0.51	−0.45	0.51	−0.26	0.34	0.69	−0.69	0.56			

Table 20 Increase of international influence: GECNFCM activation levels for targeted $A_{15} = -0.4$

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
−0.39	−0.51	0.42	−0.25	0.74	0.07	0.10	0.02	−0.05	0.05	−0.07	0.51	0.69	−0.48	−0.05	0.48

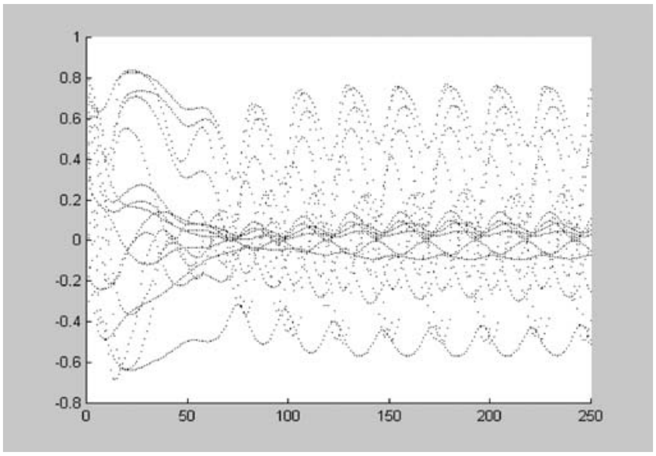

Fig. 13 Limit cycles for target $A_{15} = -0.4$

placed during the crisis period from solving the Cyprus problem to resolving the S-300 crisis.

The reluctance of the Greek side to provide active military support to the installation of the S-300 on the island is reflected in the relevant zero activation level ($A_{10} = 0.0$), unlike that of the Cypriot national guard, the activation level of which had reached $A_9 = 0.8$ revealing its adherence to the S-300 project. The Cypriot government itself does not seem to be confident enough concerning its decision to install the missiles, since its activation level drops to $A_7 = -0.53$, given the disagreement which took place between the military and the politicians over the issue. Finally, special attention should be drawn to w25 that links the stability of the Greek government (C12) to the Greek support to the Cyprus issue (C5), the weight linking the two assuming the impressive value of 0.99. This underlines the unanimity and confidence of the Greek side concerning the influence exercised upon Cyprus.

7. Conclusions

Following the presentation and construction of a FCM and a CNFCM model describing the Cyprus issue, we have introduced a hybrid model based on genetically evolved certainty neuron fuzzy cognitive maps (GECNFCMs) designed to facilitate political decision-making in the face of a crisis. The genetic algorithm of this model was used to find the optimal weight matrix that satisfies a predetermined activation level for a certain concept. The decision-maker is thus able to consider hypothetical scenarios by defining the target activation level of a concept in focus and to study the resulting weight values and activation levels once the model has reached equilibrium and the target has been met. The five scenarios simulated in this context were as follows:

Table 21 Reduction of support to Turkish forces in Cyprus: GECNFCM activation levels for targeted $A_8 = -0.2$

w1	w2	w3	w4	w5	w6	w7	w8	w9	w10	w11	w12
0.62	0.28	−0.72	−0.82	0.36	0.33	−0.60	−0.83	−0.98	0.14	0.01	0.73
w13	w14	w15	w16	w17	w18	w19	w20	w21	w22	w23	w24
−0.79	−0.21	0.57	0.08	0.20	−0.12	0.10	−0.05	0.50	−0.50	0.33	0.11
w25	w26	w27	w28	w29	w30	w31	w32	w33	w34	w35	w36
0.99	0.50	−0.29	0.86	0.86	0.93	−0.69	−0.13	0.46	0.76	0.64	0,46
w37	w38	w39	w40	w41	w42	w43	w44	w45			
−0.06	0.34	0.01	0.17	−0.49	0.50	0.70	−0.98	−0.50			

Table 22 Reduction of support to Turkish forces in Cyprus: GECNFCM activation levels for targeted $A_8 = -0.2$

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
−0.29	0.17	0.61	−0.13	−0.43	−0.40	0.51	0.21	−0.34	0.48	0.30	−0.53	0.50	−0.89	−0.01	0.72

Table 23 S-300 crisis weight values input

w1	w2	w3	w4	w5	w6	w7	w8	w9	w10	w11	w12
0.0	−0.1	0.0	0.0	0.0	−0.4	0.0	0.0	0.8	0.1	−0.3	−0.4
w13	w14	w15	w16	w17	w18	w19	w20	w21	w22	w23	w24
0.0	0.1	0.1	0.1	0.2	0.0	0.1	0.1	−0.8	−0.1	0.2	0.2
w25	w26	w27	w28	w29	w30	w31	w32	w33	w34	w35	w36
0.0	0.1	0.0	0.25	−0.3	0.1	0.2	0.0	0.0	0.1	0.1	0.0
w37	w38	w39	w40	w41	w42	w43	w44	w45			
−0.5	−0.3	0.3	0.9	−0.3	0.3	0.1	0.4	0.1			

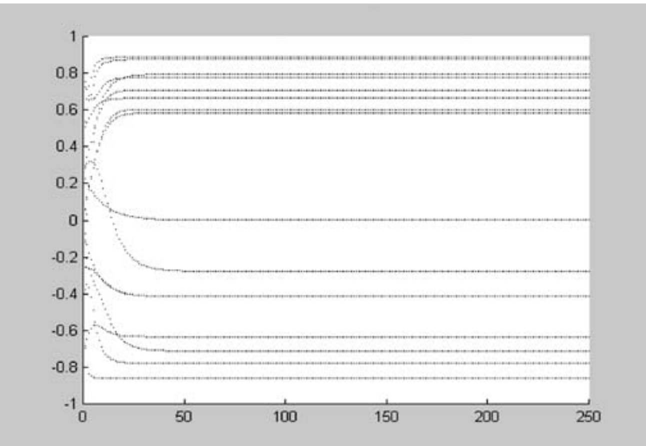

Fig. 14 Equilibrium for target $A_8 = -0.2$

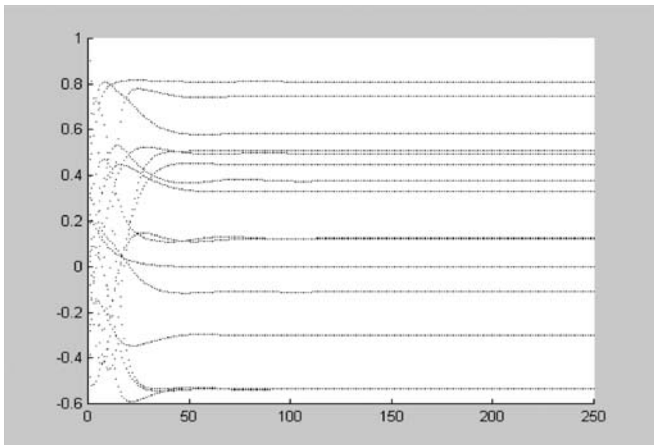

Fig. 15 S-300 crisis: GECNFCM equilibrium

Table 24 S-300 crisis: CNFCM calculated activation levels

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
0.79	0.87	0.77	−0.77	−0.41	−0.63	−0.41	0.88	0.70	0.00	0.66	0.60	−0.71	0.58	−0.85	−0.27

Table 25 Settling the S-300 crisis: GECNFCM optimal weight matrix for targeted $A_1 = 0.4$

w1	w2	w3	w4	w5	w6	w7	w8	w9	w10	w11	w12
0.10	0.60	−0.65	0.13	0.25	−0.24	−0.21	0.48	0.59	−0.70	−0.49	0.81
w13	w14	w15	w16	w17	w18	w19	w20	w21	w22	w23	w24
−0.63	−0.67	0.88	−0.41	−0.77	0.79	0.89	0.38	−0.53	−0.04	0.22	−0.32
w25	w26	w27	w28	w29	w30	w31	w32	w33	w34	w35	w36
0.99	−0.20	0.80	0.88	−0.52	0.01	0.05	−0.47	−0.62	−0.67	0.88	0.55
w37	w38	w39	w40	w41	w42	w43	w44	w45			
−0.73	−0.14	−0.50	0.27	−0.41	−0.13	−0.09	−0.41	−0.37			

The first involved an environment of escalating intensity on the island (C1), the second simulated the consequences in cases of decreased and increased solution possibilities respectively (C4), while the third investigated the case of increased/decreased Turkish threats (C3). The fourth scenario dealt with variations of the

Table 26 Settling the S-300 crisis: final activation levels for targeted $A_I = 0.4$

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
0.37	−0.53	−0.10	−0.29	0.44	0.49	−0.53	−0.53	0.80	0.00	0.50	0.58	0.12	0.32	0.74	0.12

international influence (C15), while the fifth was involved with the reduction of the support to the Turkish forces in Cyprus (C8). The results of these scenaria were quite encouraging: The GECNFCM reached the targeted activation level in equilibrium state in nearly all cases, allowing the decision-maker to forecast the dynamics of a given situation and to measure the variables determining the final state.

The hybrid system was then tested to face an actual crisis, namely the one caused following the installation of the S-300 missiles on the island. The hybrid system simulated this political situation successfully and produced results which were very descriptive of the actual events that lead to the defusion of the crisis. Thus, the validation process proved that the hybrid system proposed can be a reliable tool in the hands of political analysts and decision-makers aiming at managing a crisis or solving intricate political problems.

Finally, concerning some drawbacks of the method in cases in which the model exhibits limit cycle or chaotic behaviour, future research will focus on attempting to define the range of values for the elements of the weight matrix that drive the model to this type of behaviour.

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