Using Fuzzy Cognitive Maps as a Decision Support System for Political Decisions

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Abstract. In this paper we use Fuzzy Cognitive Maps (FCMs), a well-established Artificial Intelligence technique that incorporates ideas from Artificial Neural Networks and Fuzzy Logic, to create a dynamic model of the Former Yugoslavian Republic of Macedonia (FYROM) Crisis in March 2001. FCMs create models as collections of concepts and the various causal relations that exist between these concepts. The decision capabilities of the FCM structure are examined and presented using a model that is developed based on the beliefs of a domain expert. The model is first examined statically using graph theory techniques to identify the vicious or the virtuous cycles of the decision process. The model is also tested dynamically thought simulations, in order to support political analysts and decision makers to their political decisions concerning the crisis. Scenarios are introduced and predictions are made by viewing dynamically the consequences of the corresponding actions.

1 Introduction to Fuzzy Cognitive Maps

International Relations theory has long been concerned with Decision-Making, negotiations and crisis management [1]. Cognitive Map (CM) models were introduced by Axelrod in the late 1970s and were widely used for Political Analysis and Decision Making in International Relations [2]. The structural and decision potentials of such models were studied and the explanation and prediction capabilities were identified [2,3]. The introduction of Fuzzy Logic gave new representing capabilities to CMs and led to the development of Fuzzy Cognitive Maps by Kosko in the late 1980s [4,5]. The use of fuzzy logic allows the representation both of the type (positive or negative) of the causal relationships that exist among the concepts of the model but also of the degree of the causal relationship.

FCMs models are created as collections of concepts and the various causal relationships that exist between these concepts. The concepts are represented by nodes and the causal relationships by directed arcs between the nodes. Each arc is accompanied by a weight that defines the degree of the causal relation between the two nodes.

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The sign of the weight determines the positive or negative causal relation between the two concepts-nodes. An example of FCM is given in figure 1, showing the causal relationships that were identified in Henry A. Kinssinger's essay "Starting Out in the Direction of Middle East Peace" in *Los Angeles Times* 1982 and presented in [6].

In FCMs, although the degree of the causal relationships could be represented by a number in the interval [-1,1], each concept, in a binary manner, could be either activated or not activated. In 1997, Certainty Neuron Fuzzy Cognitive Maps (CNFCMs) were introduced [7], providing additional fuzzification to FCMs, by allowing each concept's activation to be activated just to a degree. The aggregation of the influences that each concept receives from other concepts is handled by function $f_{\mathrm{M}}()$ that was used in MYCIN Expert System [8,9] for certainty factors' handling. The dynamical behaviour and the characteristics of this function are studied in [10]. Certainty Neurons are defined as artificial neurons that use this function as their threshold function [11]. Using such neurons, the updating function of CNFCMs as a dynamic evolving system is the following:

$$A_i^{t+1} = f_M\,(A_i^t, S_i^t) - d_i\, A_i^t \tag{1}$$

where, A_i^{t+1} is the activation level of concept C_i at time step t+1, $S_i^t = \sum_j w_{ji} A_j^t$ is the sum of the weight influences that concept C_i receives at time step t from all other concepts, d_i is a decay factor and

$$f_M(A_i^t, S_i^t) = \begin{cases} A_i^t + S_i^t(1-A_i^t) = A_i^t + S_i^t - S_i^t A_i^t & if\ A_i^t \geq 0,\ S_i^t \geq 0 \\ A_i^t + S_i^t(1+A_i^t) = A_i^t + S_i^t + S_i^t A_i^t & if\ A_i^t < 0,\ S_i^t < 0 \quad \left|A_i^t\right|,\left|S_i^t\right| \leq 1 \\ (A_i^t + S_i^t) \big/ \left(1-\min\left(\left|A_i^t\right|,\left|S_i^t\right|\right)\right) & otherwise \end{cases} \tag{2}$$

is the function that was used for the aggregation of certainty factors to the MYCIN expert system.

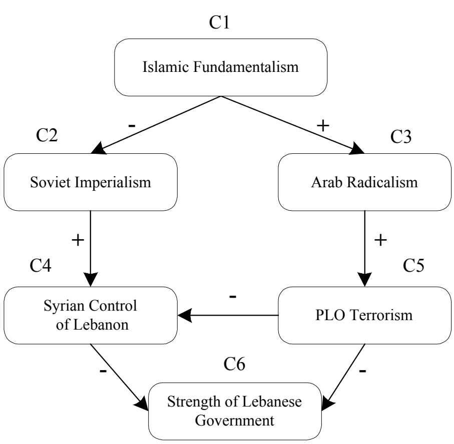

Fig.1. Henry Kissinger's FCM [6]

2 The FYROM Crisis

FYROM is one of the states created after the 1991 breakdown of the Yugoslav Federation. It is composed by two ethnic groups: Slavs and Albanians (estimated between 25 and 40%).

In the first days of March 2001 the Albanian insurgents initiated their open military and political actions against FYROM and its government, in the area neighbouring FYROM's borders with Kosovo. The actions were spread to some of FYROM's main cities, particularly where the majority of the population is Albanian. The Albanian insurgents demanded better political and economic standing for Albanians in the country. Behind that, the dream of "Great Albania" or "Great Independent Kosovo" could be hidden, especially when the political future of Kosovo is still uncertain. It was argued by politicians and international relations experts in the press that such a conflict to a new country as FYROM could cause multiple stability problems and affect the general stability of the whole Balkan region [12,13,14]. Under these conditions, voices were raised asking the international community to interfere.

FYROM's government admitted that it underestimated the power and the problems that Albanian insurgents could cause to the country and asked for better patrolling by KFOR of the borders between Kosovo and FYROM in order to reduce possible assistance by Kosovo Albanians to insurgents. FYROM's neighboring countries such as Greece and Bulgaria expressed voiced concern for a domino phenomenon, spreading war to their territories. Greece has undertaken contacts for a NATO and EU involvement seeking a peaceful settlement of the conflict. European Union countries, the USA, NATO, and even Albania stated their position that the current borders of FYROM should remain stable and gave political support to FYROM's government against Albanian insurgents.

FYROM's government for resolving the conflict, among other things, had to take into consideration the following two basic questions:

a) Will better political and economic standing of FYROM's Albanians cause the decrease of their demands or this will cause the increase of their demands, asking even for complete independence from FYROM?
b) Are Albanian insurgents supported by other third parties and to what degree? How these parties would react if FYROM asks and gets military support from other countries?

3 Development of FCM Model for FYROM Crisis

The reliability of an FCM model depends on whether its construction method follows rules that ensure its reliability. There are two main methods for the construction of FCMs :

a) The Documentary Coding method [15], which involves the systematic encoding of documents that present the assertions of a specific person for the specific topic.
b) The Questionnaire method [16,17] which involves interviews and filling in of questionnaires by domain experts.

Instability in FYROM will cause and to what degree to the following:	Very Big		Big		Moderate		Small		Very Small		No
Political support from NATO											
Financial Support from Greece											
Appeasement from FYROM's government											
……											
Numerical weights	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0

Fig.2. Part of the questionnaire concerning FYROM crisis

For our case we used the second method, interviewing and also supplying with questionnaires a domain expert. The domain expert was a faculty member of the Department of International & European, Economic & Political Studies of the University of Macedonia. During the interviews, the concepts that should be included in the model were identified. In questionnaires the causal relationship that exist between these concepts were defined by the expert, accompanied by the degree to which a concept influence each other concept. The format of the questionnaire is given in Figure 2.

The expert had to fill in with + or – whether he believed that there is a positive or negative causal relationship between the concepts. The degree of these causal relationships was captured by allowing the expert to fill in the sign in one of the fields "Very Big", "Big", "Moderate", "Small", "Very Small". These linguistic values could be transformed into numerical weights by assigning weights from the interval [0,1] according to the way that is shown in figure 2. If according to his believe there is no causal relationship, the field "none" could be checked. After studying the questionnaires and taking the weights identified by expert, the model presented in figure 3 was developed. In figure 3, only the signs of the arcs-causal relationships are shown. The weights of the arcs are given in Appendix A. The model created is studied both statically and dynamically.

4 Static Analysis

The static analysis of the model is based on studying the characteristics of the weighted directed graph that represent the model, using graph theory techniques. The most important feature that should be studied is that of the feed back cycles that exist in the graph. Each cycle is accompanied by a sign, identified by multiplying the signs of the arcs that participate in the cycle. Positive cycles behaviour is that of amplifying any initial change, leading to a constant increase in case an increase is introduced to the system. This is why they are also called deviation amplifying cycles [18], augmenting cycles [17] or vicious cycles [19], [18], [20]. An example of a positive/vicious cycle is that of C1(Albanians insurgents actions in FYROM) ⇨ C5 (Instability in FYROM) ⇨ C14 (Military support from Greece) ⇨ C3 (Support to Albanian insurgents from other third parties) ⇨ C1(Albanian insurgents actions in FYROM). Through this cycle the "Instability of FYROM" will constantly increase.

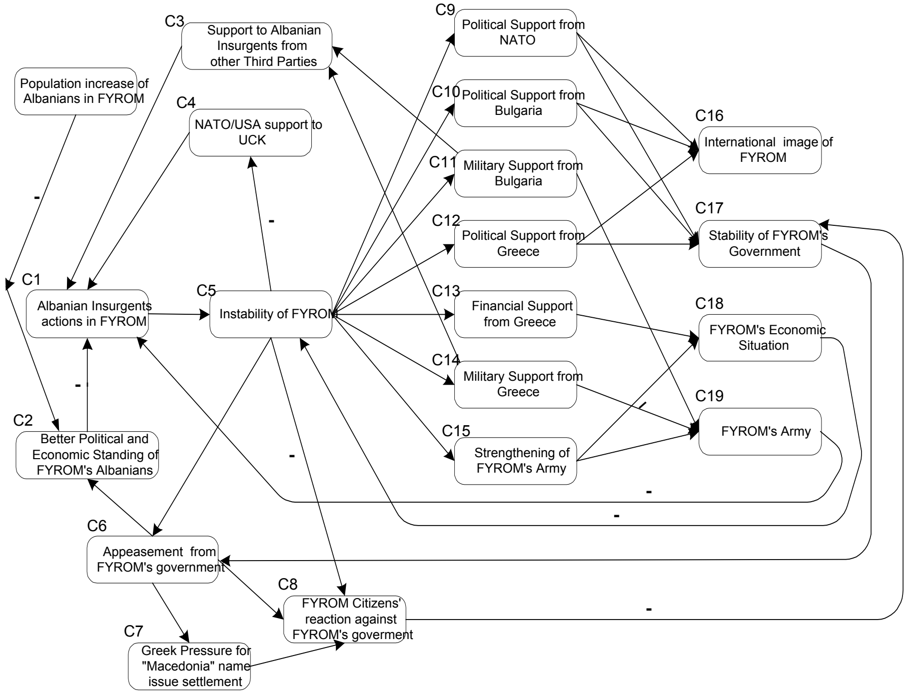

Fig.3. FYROM's crisis FCM model

Negative cycles on the other hand, counteract any initial change. This means that they lead to decrease in the case where an increase is introduced in the cycle. Negative cycles are also called deviation counteracting cycles [18], inhibiting cycles [17] or virtuous cycles [19], [18], [20]. An example of a negative/virtuous cycle is that of C1 (Albanian insurgents actions in FYROM) ⇨ C5 (Instability in FYROM) ⇨ C14 (Military support from Greece) ⇨ C19 (FYROM's Army) ⇨**(-)** C1 (Albanian insurgents actions in FYROM). Through this cycle the "Instability of FYROM" will constantly decrease. The model of Figure 3 is rich of cycles. All cycles appear in Table I

In Table I the signs of the cycles are shown for two scenarios. In scenario #1, the weight w21 that connects Concept 2 ("Better Political and Economic Standing of FYROM's Albanians") to Concept 1 ("Albanian insurgents' actions in FYROM") is negative. This means that if FYROM's government measures provide better political and economic standing to FYROM's Albanian population, there will be a decrease of Albanian insurgents' actions. In this case the FCM model has eleven negative (deviation counteracting) cycles and three positive (deviation amplifying) cycles, showing a preference towards moderation.

In scenario #2, the weight w21 is positive, meaning that if FYROM's government measurements provide better political and economic standing to FYROM's Albanians, there will be an increase of Albanian insurgents' actions, asking for even more. In this case the FCM model has seven negative (deviation counteracting) cycles and seven positive (deviation amplifying) cycles, showing strong interactions among the concepts of the model and instability. Four cycles changed sign if compared with scenario #1 and they appear shadowed in Table I. All fourteen cycles exist concurrently in domain expert's mind. Which of the cycles will prevail is difficult to know even for model with much less cycles. Additionally, it is difficult to make scenarios, predictions and draw conclusions, having all these cycles in mind. For this reason, dynamical analysis and simulations are required.

Table 1.

	Cycles	**Scenario #1 (w21 : negative)**	**Scenario #2 (w21 : positive)**
1	C5 ⇨C9 ⇨ C17 ⇨ C6 ⇨ C2 ⇨ C1 ⇨ C5	-	+
2	C5 ⇨C10 ⇨ C17 ⇨ C6 ⇨ C2 ⇨ C1 ⇨ C5	-	+
3	C5 ⇨C12 ⇨ C17 ⇨ C6 ⇨ C2 ⇨ C1 ⇨ C5	-	+
4	C5 ⇨C11 ⇨ C19 ⇨ C1 ⇨ C5	-	-
5	C5 ⇨C14 ⇨ C19 ⇨ C1 ⇨ C5	-	-
6	C5 ⇨C15 ⇨ C19 ⇨ C1 ⇨ C5	-	-
7	C5 ⇨C13 ⇨ C18 ⇨ C5	-	-
8	C5 ⇨C15 ⇨ C18 ⇨ C5	+	+
9	C5 ⇨ C6 ⇨ C2 ⇨ C1 ⇨ C5	-	+
10	C5 ⇨ C4 ⇨ C1 ⇨ C5	-	-
11	C5 ⇨ C11 ⇨ C3 ⇨ C1 ⇨ C5	+	+
12	C5 ⇨ C14 ⇨ C3 ⇨ C1 ⇨ C5	+	+
13	C17 ⇨ C6 ⇨ C7 ⇨ C8 ⇨ C17	-	-
14	C17 ⇨ C6 ⇨ C8 ⇨ C17	-	-

5 Dynamical Analysis

After some indications for stability or instability that were found from the static analysis of the model, conclusions will be drawn by simulating. The model of figure 3 was simulated using the CNFCM technique that was mentioned in section 1. Initially the weight w21 was set to a negative value (scenario #1 of Table I). The initial values of the activation levels of all the concepts in the model were determined by the domain expert. The concepts of the system were left free to interact and the nineteen concepts of the system reach equilibrium at zero after almost 250 iterations. The transition of the system to equilibrium is shown in fig 4.

The study of the transition phase of the FYROM's crisis CNFCM has shown that the strength of the negative cycles that counteracted any cause of instability in FYROM was such that led to equilibrium at zero. The support (political, financial and military) that FYROM received from third parties (NATO, Greece, Bulgaria) gave stability to FYROM's government, strengthened its economic situation, and through the actions of FYROM's army the actions Albanian insurgents were ceased. Furthermore FYROM's government took measures for better political and economic standing of FYROM's Albanians. In this way, part of the demands of the Albanians were satisfied, limiting the support of FYROM's Albanians to Albanian insurgents. The support of other third parties to Albanian insurgents did not manage to maintain insurgents' actions.

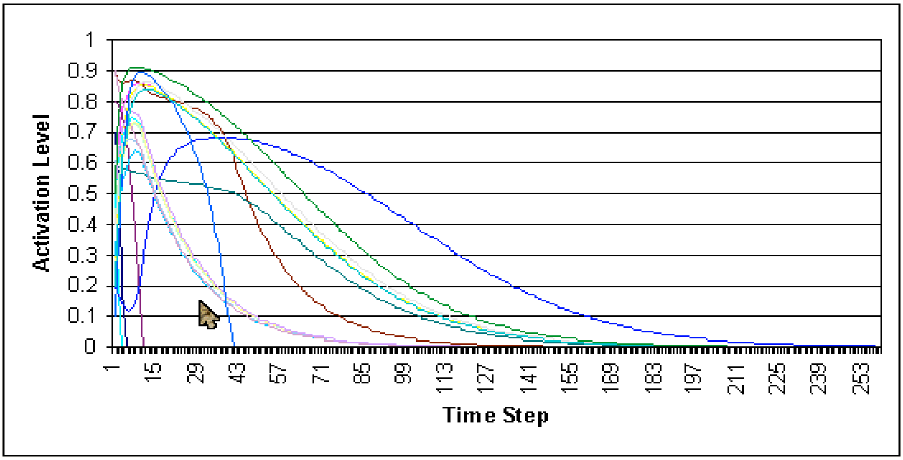

Fig.4. Transition phase of FYROM's crisis CNFCM. System stabilizes at zero (scenario #1: w21 is negative)

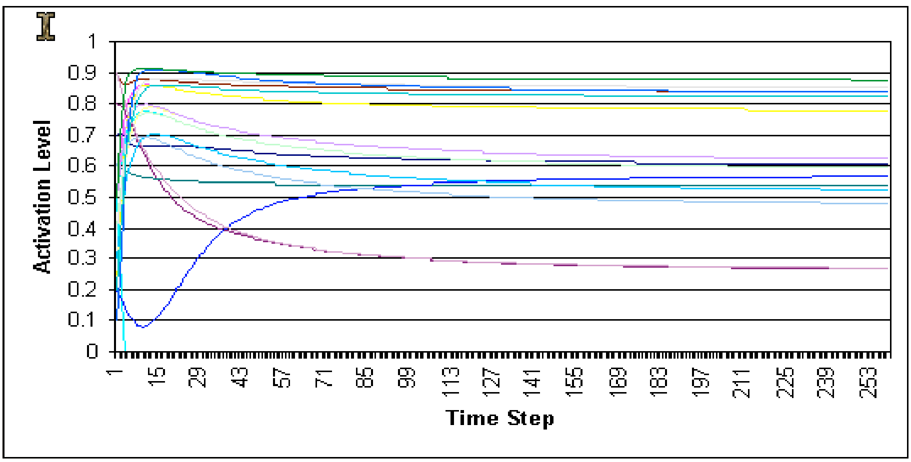

Fig.5. Transition phase of FYROM's crisis CNFCM. System stabilizes at no zero (scenario #2: w21 is positive)

The second scenario that was suggested by the expert and introduced to the system is that of scenario #2, where weight w21 is positive, meaning that actions from FYROM's government towards better political and economic standing of FYROM's Albanians will be taken as a proof that violence did its work and so Albanians will ask for even more rights. Simulation of this scenario, using the CNFCM technique, give the results of Figure 5.

Now the dynamic behaviour of the system is different. The system reaches once again equilibrium but not at zero. On the contrary, all concepts have an activation level in the interval [0,1] that represent the degree of each concept's activation. The equilibrium point, with the activation levels of all concepts at equilibrium, is given in

Appendix B. It should be noticed that the system stabilizes with FYROM being instable. Concept "Instability of FYROM" has an activation level 0.259 that means there is some instability despite the measures that FYROM's government takes and the support that FYROM receives from NATO, Greece and Bulgaria. The main reason for this is that the support to FYROM's government from Greece and Bulgaria causes other third part countries to support Albanian insurgents. Furthermore, the increase of the population of Albanians in FYROM is another reason for constant instability, as indicated by the expert. This constant instability will change when some concepts or causal relationships of the model are affected by a factor external to the model.

Another suggested scenario was introduced to the model, testing the stability of the system according to the degree of the support that Albanian insurgents receive from other countries. In this third scenario, as in scenario #2, the weight w21 is positive, but now the support that Albanian insurgents receive from other countries is less (weight w31 changed from 0.5 to 0.2). The transition phase of the simulation of this third scenario is given in figure 6. Like scenario #1, the system reaches equilibrium at zero, meaning that Albanian insurgents actions in FYROM are ceased. This means that even if, when FYROM's government gives rights to Albanians and FYROM's Albanians ask for more, the battles of Albanian insurgents will cease if they are not well supported by other third parties.

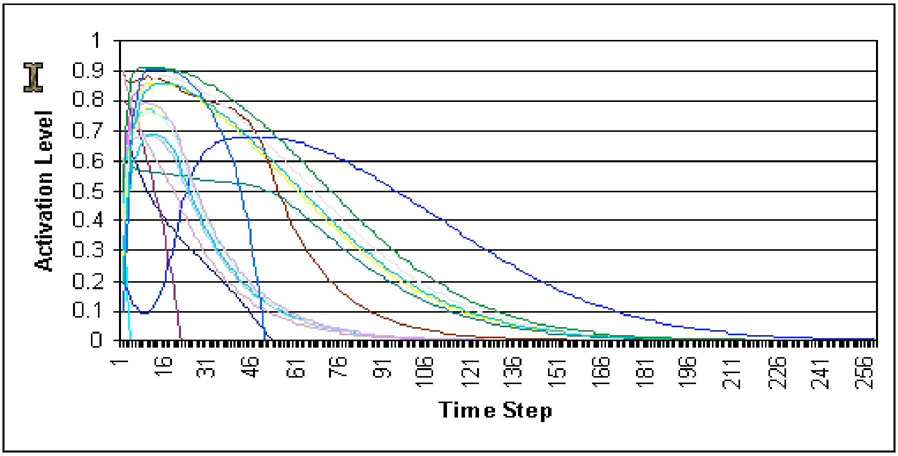

Fig.6. Transition phase of FYROM's crisis CNFCM. System stabilizes at zero (scenario #3: w21 is positive, w31 decreased to 0.2)

6 Summary – Conclusions

Using the FCM method, a model was created for FYROM's crisis in March 2001, based on the opinion of a domain expert. The model was examined statically and the signs of model's fourteen cycles were identified. Using the CNFCM technique for simulations, three scenarios were introduced to the model. Through the study of the simulations, the conclusions that were drawn and concern the FYROM crisis are the following:

The model predicted a different outcome of the crisis, depending on :

a) whether providing of better political and economic standing for FYROM's Albanians by FYROM's government will cause decrease of Albanian insurgents' actions (since their demands are even partly satisfied, FYROM's Albanian citizens do not support any more actions by insurgents) or increase of Albanian insurgents' actions (since they see that violence had an effect and so they ask for more).
b) the degree to which other third parties support Albanian insurgents, especially when FYROM gets support by countries such as Greece, Bulgaria or by NATO.

So before any decision is taken, a good estimation of these factors is vital for making the right decisions. Apart from just making estimations of these factors, in a more drastic manner, measurements can be taken to affect these key factors for the crisis outcome. In this way political decisions can be taken and supported by a CNFCM model.

In this study, CNFCM technique was found capable of providing decision makers and political analysts with a decision support system. The CNFCM flexible structure proved suitable for making political decisions in fuzzy and uncertain situations like political crisis. Predictions can be made and scenarios can be introduced and tested through simulations. The important key for the success of an FCM model remains the validity of the knowledge that is extracted from domain experts and is used for the creation of the model.

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Appendix A – Weights of Causal Relationships between Concepts

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19
C1	0	-0.8	0.5	0.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.9
C2	0	0	0	0	0	0.8	0	0	0	0	0	0	0	0	0	0	0	0	0
C3	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0.8	0	0	0	0	0
C4	0	0	0	0	-0.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C5	0.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.6	0
C6	0	0	0	0	0.7	0	0	0	0	0	0	0	0	0	0	0	0.7	0	0
C7	0	0	0	0	0	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0
C8	0	0	0	0	-0.5	0	0.6	0	0	0	0	0	0	0	0	0	0	0	0
C9	0	0	0	0	0.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C10	0	0	0	0	0.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C11	0	0	0	0	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C12	0	0	0	0	0.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C13	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14	0	0	0	0	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15	0	0	0	0	0.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C16	0	0	0	0	0	0	0	0	0.9	0.2	0	0.4	0	0	0	0	0	0	0
C17	0	0	0	0	0	0	0	-0.8	0.8	0.5	0	0.8	0	0	0	0	0	0	0
C18	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0.7	0	0	0	0
C19	0	0	0	0	0	0	0	0	0	0	0.7	0	0	0.7	0.7	0	0	0	0

Appendix B – Equilibrium Point of scenario #2

Activation Level	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19
	0.604	0.777	0.777	0	0.259	0.841	0.537	0.570	0.517	0.588	0.588	0.617	0.472	0.263	0.617	0.851	0.837	0.821	0.876