Strategic Planning Using Extended Fuzzy Cognitive Maps

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Abstract: Strategic planning can be partially automated by using knowledge captured from experts and employing specific inference techniques. Fuzzy Cognitive Maps (FCMs) is such a method which creates models as a collection of concepts and of various causal relationships that exist between concepts. Scenarios can be built and by means of FCMs' dynamical behaviour, prediction of the consequences becomes possible. The predicted outcome can serve for the determination of the suitable strategy. Extended Fuzzy Cognitive Maps (EFCMs) have been proposed by the authors. A new kind of feedback is performed in the system by the introduction of memory and decay mechanisms and the representing capabilities of the models are increased. The EFCM design is presented by means of an example application.

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1. Introduction

The success of today's industrial companies depends on their ability of fast and reliable decision-making. These decisions should be consistent with a strategic plan that the company has developed, based on various factors and criteria and which should be followed during all phases of the product life- cycle. Decision support methods attempt to partially automate the strategic planning process by applying various inference methods and knowledge that has been extracted from domain experts. Predictions are made and the consequences of decisions can be checked to see if the objectives of the decision are met.

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Cognitive Maps have been introduced by Axelord [1] and attempt to emulate the human cognitive processes during decision-making. A Cognitive Map is a signed directed graph where nodes are various concepts and arcs are causal relationships that exist between the concepts. A positive arc from concept A to concept B means that A causally increases B. A negative arc from concept A to concept B means that A causally decreases B. To develop such a graph, extended knowledge extraction should be made. Experts on the particular area of application are interviewed and the causalities between the concepts are identified. Having developed the cognitive map, the user can exploit it as an inference mechanism initialisation. This is achieved by the system initialization with the current state of the concepts and , following the causal connections, by the analysis of the influences exerted on various concepts of the system. Methods for cognitive maps simulation and also the necessary mathematical foundations are given in [1].

Software systems that can develop Cognitive Maps and analyse their decisions have been proposed [2],[8]. Furthermore special cognitive maps of decision-makers have been created [4] and new ideas such as clustering and preprocessing, are introduced to Cognitive Maps [5].

2. Fuzzy Cognitive Maps

With the development of Fuzzy Logic and Fuzzy Systems new trends appeared in all the areas where uncertainty was an important factor of the problem. This led to the development of Fuzzy Decision-Making [6] and also to the introduction of Fuzzy Cognitive Maps (FCMs). They are a combination of Fuzzy Logic and Recurrent Neural Networks. They were introduced by B. Kosko [7],[8], based on the work of Axelord in Cognitive Maps [1]. They are fuzzy signed directed graphs with feedback. The arcs of the graph are not only signed but also weighted. This signifies that not only the type (positive or negative) of the causal relationship but also the degree of the relation is represented, enabling a better representation of the real world problem.

Each node-concept C_i is accompanied by a number A_i that represents its level of activation. The activation level is calculated by the following rule:

$$A_i^{t+1} = f(S_i^t) \qquad (1)$$

$$\text{where } S_i^t = f\left(\sum_{\substack{j=1 \\ j \neq 1}}^{n} A_j^t w_{ij} \right) \qquad (2)$$

A_i^{t+1} is the activation level of concept C_i at time t+1, A_j^t the activation level of concept C_j at time t, W_{ji} the weight of the arc fromC_j to C_i and f() a threshold function, so that the activation takes one value among the allowed distinct values (usually 0 and 1 or -1,1).

The important feature of this structure which other inference methods are deprived of is that cycles in the graph are allowed. This means that feedback is allowed and experts can freely draw causal pictures of their problem without being constrained by the necessity of acyclicity. Cycles in general raise a problem in reasoning since they can yield infinite loops. This is the reason why Expert Systems allow for the use of only tree structures, which is easy to follow by the system but is not the right representation for the expert. FCMs method is an alternative to classical Expert Systems, which allow cycles and can be considered as a Parallel Fuzzy Expert System.

The inference mechanism of FCMs is the following [8],[9]: first the FCMs should be initialized. The activation level of each node of the systems is set to -1 or 1 based on the expert beliefs of the current state. Afterwards the various concepts are free to interact. The activation of one node influences the nodes which it is connected to. This interaction continues until :

(i) A fixed point equilibrium is reached. In this case some concepts are activated and some others are not.

This final state is the state that our system is going to move to and so prediction can be uttered.

(ii) A limit cycle is reached. In this case the activation level of each node changes periodically.

(iii) Chaotic behaviour is exhibited [9].

3. Extended Fuzzy Cognitive Maps

Extended Fuzzy Cognitive Maps have been proposed by the authors [10]-[12], where concepts are augmented with memory capabilities and decay mechanisms. The new activation level A_i^{t+1} depends not only on the sum of the weighted influences but also on the current activation A_i^t, i.e. $A_i^{t+1} = F(A_i^t, S_i^t)$. Thus it is possible to capture the behaviour of various concepts, whose state depends not only on the influences exerted on them but also on their previous state (e.g. it is more difficult to activate an already activated concept). The function F() chosen for the proposed design procedure consists of two parts and is of the following form:

$$F(A_i^t,S_i^t)=f(A_i^t,S_i^t)-d_iA_i^t \tag{3}$$

The function f() was introduced by the MYCIN expert system [13] and is given by:

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

This two-variable function returns the certainty factor of a fact, after receiving new evidence for or against our previous belief. Its physical meaning for a concept is that the external influence on a concept can affect its activation just to the degree of keeping not activated. The second term $-d_iA_i^t$ of function F() introduces a decay mechanism on the activation of the concepts. The decay factor d_i can take any value within the interval [0,1]. According to the above decay mechanism, at each time step a fraction of the current activation is subtracted from the initial new activation as calculated by f(). The inference method is the same with that of FCM but the predictions are enhanced due to the fact that now activations can take any value within the interval [-1,1].

It should be noticed that in the system there is no direct connection between a node and itself ($w_{ii}=0$). If such a kind of a feedback were introduced, the system would exhibit binary, crisp behaviour as in the classical FCMs. In the system, feedback exists internally in the neural structure itself since the updating function F depends on both A_i^t and S_i^t. Thus the current state A_i^t influences independently and critically the updated state in a manner which resembles automata.

4. Case Study

The capabilities of EFCM for Strategic Planning are examined by means of an example application in car industry. The used Cognitive Map is a modified version of that version presented in [14] and looks like in Figure 1. The map consists of the following seven concepts: High Profits, Customer Satisfaction, High Sales, Union Raises, Safer Vehicles, Foreign Competition and Lower Prices. The causal relationships that exist between the concepts are shown in the weight matrix of the graph (see Table 1).

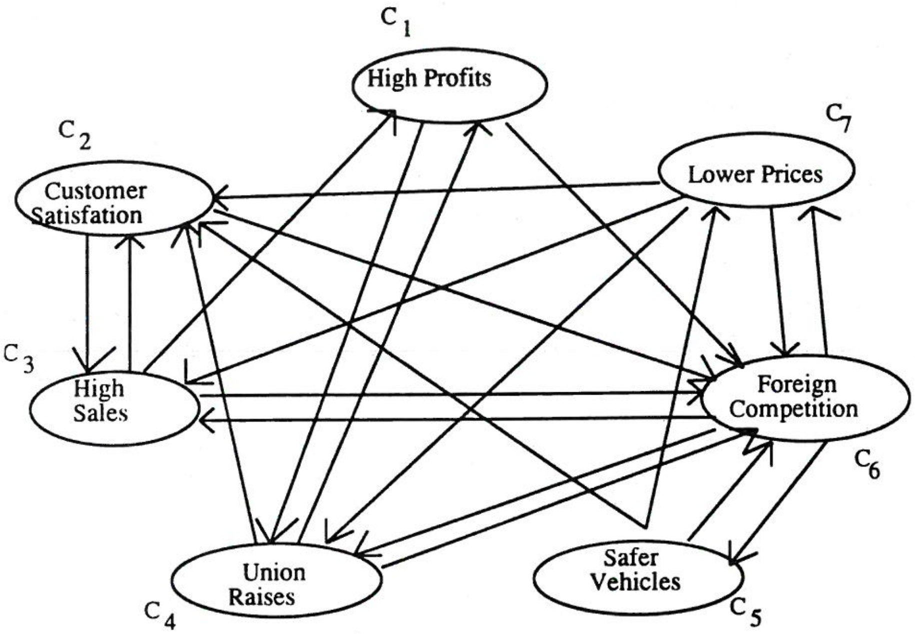

Figure 1. The Cognitive Map for Car Industry

Tabel 1. The Weight Matrix of the Graph

	High Profits	Customer Satisfaction	High Sales	Union Raises	Safer Vehicles	Foreign Competition	Lower Prices
High Profits	0	0	0	0.8	0	0.9	0
Customer Satisfaction	0	0	0.7	0	0	-0.4	0
High Sales	0.98	0.3	0	0	0	-0.4	0
Union Raises	-0.4	-0.6	0	0	0	0.3	0
Safer Vehicles	0	0.8	0	0	0	0	-0.5
Foreign Competition	0	0	-0.8	-0.7	0.3	0	0.5
Lower Prices	0	0.8	0.7	-0.4	0	-0.5	0

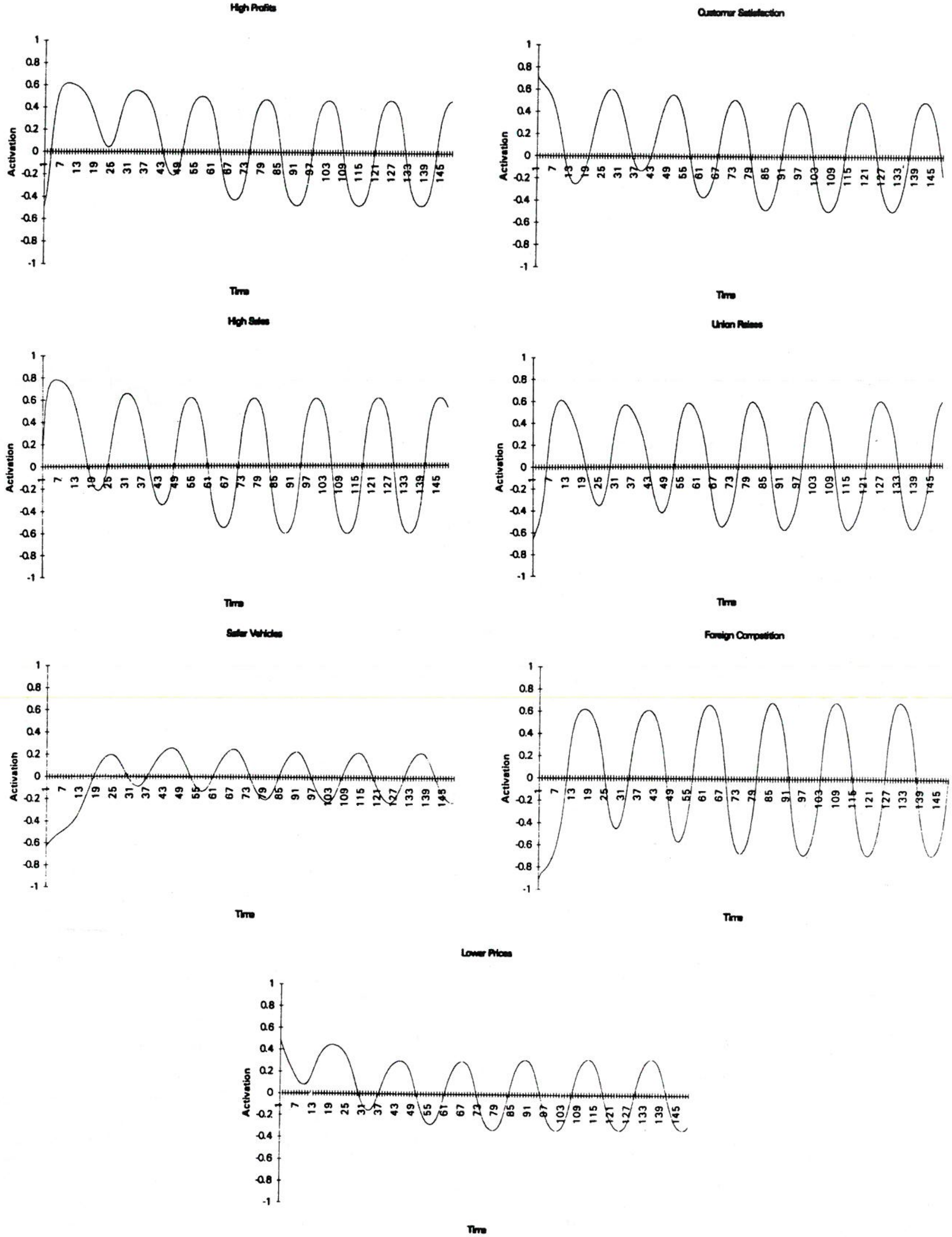

Figure 2. Free Interaction Between the Concepts

It should be stressed that the Fuzzy Cognitive Map is fully designed by the expert and represents his beliefs. It is common that different experts have different opinions and this can cause some problem to the design of the map. Several attempts have been made at increasing the reliability of weight matrix W. According to Kosko [8] a way of achieving this is by consulting more than one expert. Assume that N experts are consulted and their expertise has been scored with a value from 1 to 10. If s_i is the score of expert i and if according to him W_i is the matrix of the FCM, then the final matrix is given by the following formula :

$$W = \sum_{i=1}^{N} s_i W_i \;/\; \sum_{i=1}^{N} s_i$$

This way opposite beliefs are eliminated and a more generally accepted matrix is received.For simulations the map in Figure 1 will be used. Free interaction is allowed between nodes, which means that the activation of the concepts is free to take any value from -1 to 1. If initializing the system with values for each concept best representing the current state in the expert's opinion, the extended FCM will reach an equilibrium of a limit cycle. The conclusion is that if all the nodes were not influenced by an external factor but those of the FCM, the car industry would not reach an equilibrium point with the activation level of all nodes periodically changing. This behaviour is shown in Figure 2.

Let us now try to use the EFCM for predicting what will happen in the following scenario. For some reasons the employees of the company go on strike. This means that the "Union Raises" concept strengthens and is set to a positive degree (+0.8). On introducing this value to the EFCM concept, the system changes its dynamical behaviour from limit cycle to a fixed point equilibrium. The transition to the equilibrium is shown in Figure 3 and the equilibrium point is the following:

High Profits	Customer Satisfaction	High Sales	Union Raises	Safer Vehicles	Foreign Competition	Lower Prices
-0.746	-0.416	-0.629	0.800	0.324	0.512	0.226

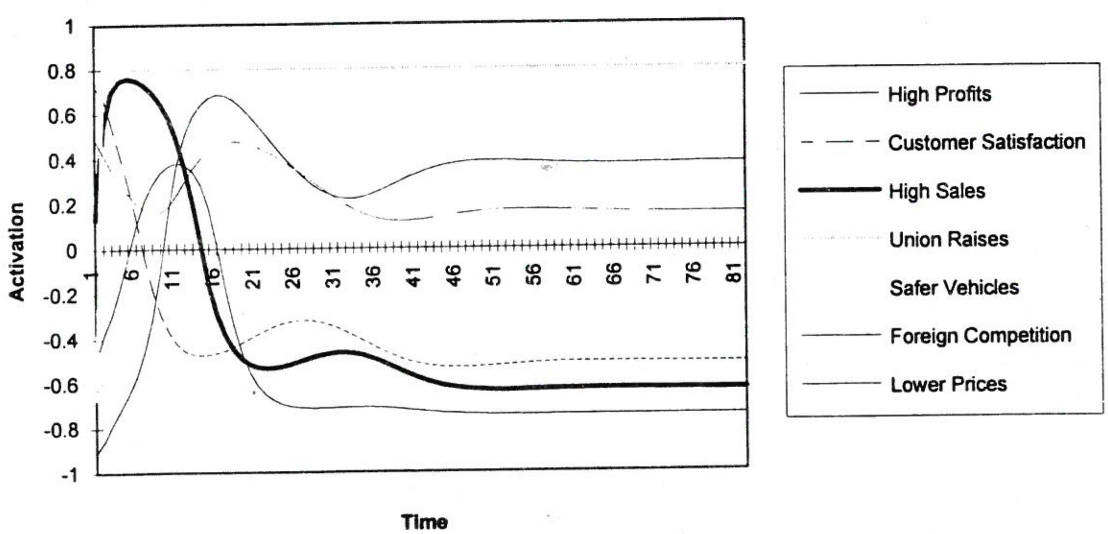

Figure 3. "Union Raises" set to +0.8.

The consequences for the car company are severe. There is a serious decrease in profits, customer satisfaction and sales. The company's only reaction is to lower prices and improve car's safety in an attempt to infer customer satisfaction. Furthermore, the foreign competition gets severer. This prediction shows that currently the company is very sensitive to strikes. It should try to find a way to overcoming this weakness. Let us imagine that by some means (e.g. advertisement) the car company has changed the causal relationship between "Union Raises" and "Customer Satisfaction" from -0.6 to -0.1. With this new weight and "Union Raises" set once again to 0.8, the system reaches, as shown in Figure 4, a different equilibrium point which follows.

High Profits	Customer Satisfaction	High Sales	Union Raises	Safer Vehicles	Foreign Competition	Lower Prices
0.070	0.493	0.351	0.800	0.285	0.425	0.124

Now the consequences of strikes are quite different. The company lowers the prices and keeps the customer satisfaction to a high degree. The sales continue to be high although the foreign competition is fierce. The safety of cars has also a positive value and finally the profits of the company maintain at the same level. The conclusion is that in order that the company should be able to cope with strikes, it should find mechanisms capable of reducing the negative influence that strikes have on customer satisfaction.

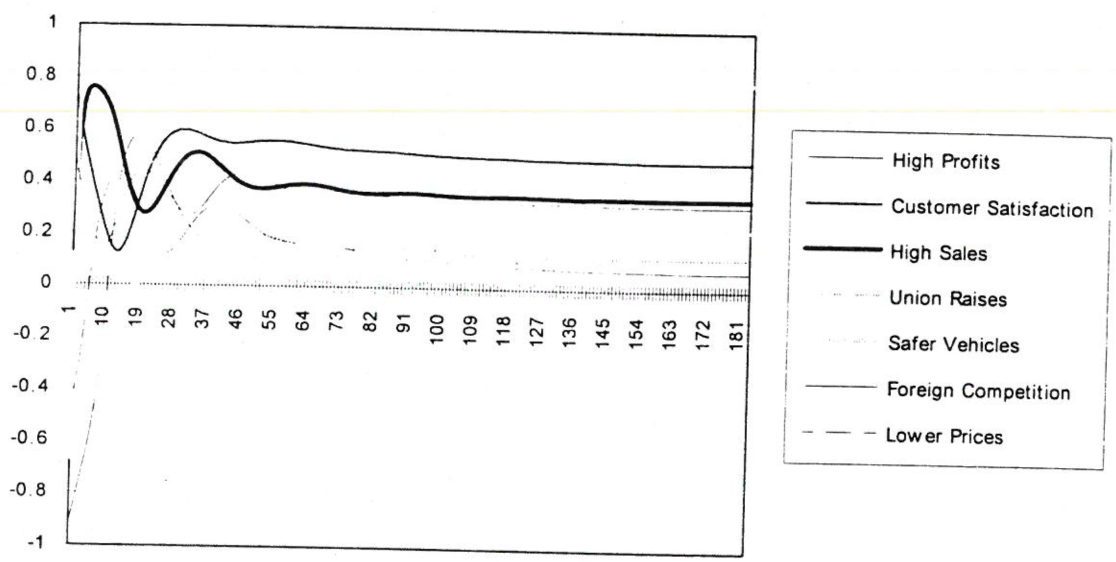

Figure 4: "Union Raises" set to +0.8 with modified map.

A second scenario based on the same map is the following: the current causal relation between "Foreign Competition" and "Lower Prices" is defined to +0.5. Let us imagine that now discounts are difficult to be made and the above causal relation is changed to +0.1. It would be interesting to see what the consequences of a serious increase in "Foreign Competition" might be on all the concepts of our model. If we set "Foreign Competition" to 0.75, the system will reach the following equilibrium point, as shown in Figure 5.

High Profits	Customer Satisfaction	High Sales	Union Raises	Safer Vehicles	Foreign Competition	Lower Prices
-0.469	0.522	-0.578	-0.710	0.413	0.750	-0.291

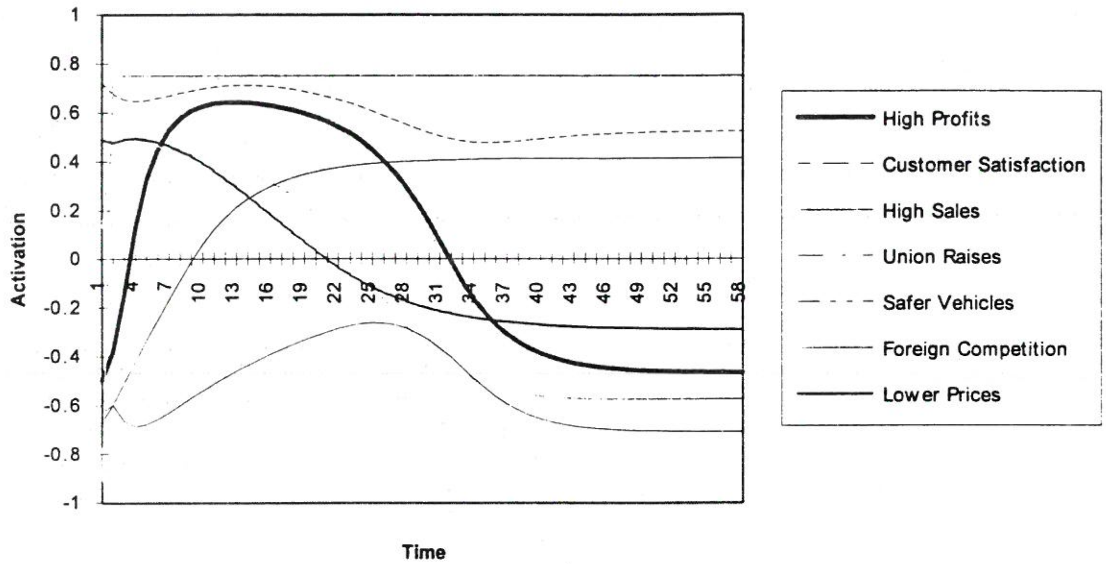

Figure 5. "Foreign Competition" set to +0.75.

The consequences are the following. Although the safer cars' design and customer satisfaction are highly met, there will be a serious diminishing of profits and sales. The company should, in order to overcome this, try to change some weights of the matrix so that a positive outcome for the company should configure. If the causal relations between "Foreign Competition" and "Lower Prices" is set to its initial value (0.5), then the system yields the following equilibrium state (Figure 6).

High Profits	Customer Satisfaction	High Sales	Union Raises	Safer Vehicles	Foreign Competition	Lower Prices
0.598	0.743	0.336	-0.366	0.413	0.750	0.354

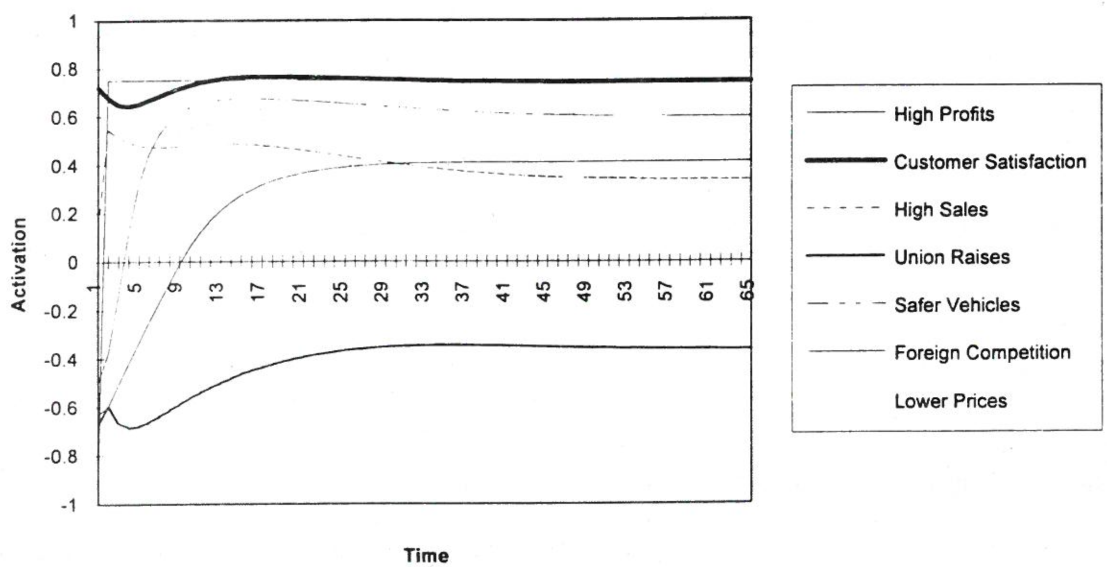

Figure 6. "Foreign Competition" set to +0.75 with modified map.

The conclusion is that although at present there is a strong Foreign Competition, the profits of the company are high. The same applies to "Customer Satisfaction" and "High Sales". "Union Raises" is getting lower and safer cars are manufactured. The prices get smaller as well. This means that the company should, in order to overcome the problem , try to reduce the extent to which foreign competition may influence the car prices.

5. Conclusions

This paper has studied the structure of Fuzzy Cognitive Maps for Strategic Planning . Their ability of graphically representing causal relationships between objects-concepts and their dynamic way of evolving, make them quite suitable for planning. The consequences of decisions can be predicted and accounted for. EFCMs enhance these capabilities by allowing a decimal activation all through the interval [-1,1] instead of the two values -1,1. All this is possible by introducing decay mechanisms and a new updating function which allow a special kind of feedback. The above was demonstrated by an example application.

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