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Extended summary

Fuzzy Cognitive Maps tools for Industrial Engineering

Curriculum: Energetica

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Abstract. The proposed thesis highlighted the potential of cognitive maps in their explanatory and reflective functions and their value in support of decision making within organizations in a phase of any consolidation of the cognitive distances involved. Intelligent agents use mental models and have various “internal” processes (physical, mental, emotional) as they interact with other agents. Encourage group members to produce their own learning and cognitive maps represent their mental models that can have multiple functions in the formation, whether or not assisted by the network. The considered areas of study are characterized by complexity requiring the investigation of new advanced methods for modelling and development of sophisticated systems. In order to improve the communication between the different actors in relation to the factors, it becomes important to recognize that the mental models that characterize them influence the way they perceive the world and, consequently, the risks. The information collected through this analysis have been used both as a basis for the definition of strategies of risk communication, and as a guide for the negotiation process aimed at reducing existing levels of conflict and, at improving the mitigation measures to be taken. On the basis of the results obtained, it becomes important to encourage administrators to increase the dissemination of information about previous responsibilities relating to risk management, and the future ones relating to possible measures to be undertaken in a specific area. The proposed PhD thesis analyses some cases of study. It has been described the application of the FCM in the suppliers' selection sector, specifically, in the new product development process; in the analysis of injury events on workplace, where the social aspect has a great relevance; it has been analysed in order to define a new ranking method, in an Italian company, for defining a criticality indicator for the equipment and a proper maintenance program and, finally, the FCM has been applied in the Healthcare sector and, specifically, it has been used to define the main causes affecting the drug administration risk.

Keywords. Intelligent Agent, Fuzzy Cognitive Map, Team Working.

1 Introduction

In the industrial plant sector, every process has been analysed without considering a relevant aspect: who works in an industrial plant.

The social aspect of this problem must be considered one of the most important factors for the improvement of any process. At the same time, it is important to consider the workers' experience and approach to any problem in order to define a proper solution. For these reasons, the application of Fuzzy Cognitive Map (FCM) could be a very powerful tool for developing a social approach to various industrial plant problems. In particular, when the analysis of a problem is complex and difficult, FCM allows for a more simple design model. In fact, in the presence of a large number of variables, or lack of information about the problem, they could be used referring to the workers' experience. It is not always possible to model a problem in mathematical terms, but it is always possible to define it using the FCM. This is possible because, using fuzzy logic, FCM allows for the representation of a problem in terms of "natural language". Daily, our brain summarises different information in order to solve a problem or take a decision. In 1973, L.A. Zadeh observed that one of the most important capabilities of the human brain is to summarise information. A summary is, by its nature, an approximation of the reality, and the human brain takes advantage of this imprecision tolerance through the coding of the relevant information with respect to a specific need.

In analysing masses of data and complex phenomena, human demonstrate an innate ability to make an efficient decision under conditions of uncertainty and imprecision. All these processes of reasoning are based on perceptions that are the basic units of knowledge. Such perceptions are united by certain properties such as bias, dependence on context and the fine granularity. In the latter case it refers to the fact that humans tend to structure the information in granules, i.e. categories of objects grouped by common characteristics such as similarity, indistinguishability and proximity. This is what determines the superiority of human reasoning on the mathematical approach: the tolerance for imprecision and the ability to synthesize, i.e. to extract information from a large number of the subset of data needed to make a rational decision. The proposed approach uses the fuzzy logic.

Through the use of fuzzy logic it is possible to represent an atomic element, concept, event, to belong to multiple sets apparently exclusive. But one of the essential characteristics of the fuzzy world is that it focuses on the interactions, human relations, imagination, and points to a model of flexible person that adapts to change.

In addition, Zadeh said that the key elements of human thinking are not numbers but labels of fuzzy sets. The dynamic processes, characterising the thought and human actions can be effectively modelled by a fuzzy concept map (FCM). In so doing, it allows the construction of a semi-quantitative model that provides qualitative explanations of facts also very complex with several fuzzy variables, some of which are not known. FCM was introduced by B. Kosko (1986). According to which it is possible to interpret a cognitive scheme as a neural network in which each concept is activated depending on the connections with antecedents concepts.

This tool has proven particularly useful for simulating complex processes and to validate hypothesis of correlation between cause and effect, which are difficult to obtain using mathematical models and the traditional logic.

In order to give a depth view of the FCM, the proposed PhD thesis has been organised as follow: Section 2 describes the FCM theory proposed by Kosko and, subsequently, revised by Carvalho in order to have a better fuzzy realisation of a cognitive map. Section 3 analyses the application of the FCM in the suppliers' selection sector; in the definition of a criticality indicator for the equipment and a proper maintenance program in an Italian refinery. Finally, in the Conclusion section, a brief summary about the FCM application in the mentioned sectors has been reported.

2 The Fuzzy Cognitive Map Theory

2.1 The Fuzzy Cognitive Method

Fuzzy Cognitive Maps (FCMs) are fuzzy signed graphs with feedback (Stylios et al., 1997). FCMs consist of nodes, also named concepts C_i, and interconnections e_{ij} between concept C_i and C_j. A Fuzzy Cognitive Map models a dynamic complex system as a collection of concepts and cause and effect relations between concepts. Interconnections e_{ij} among concepts are characterized by a weight w_{ij} that describes the grade of causality between two concepts. Weights take values in the interval *[-1 1]*. Hitherto, Simple FCMs have edge values in {*-1 0 1*} as proposed by Stylios et al. (2004). In particular, the sign of the weight indicates the type of causality. In fact, if $w_{ij}>0$ between concept C_i and C_j a positive causality exists, which means that an increase of the value of concept C_i will cause an increase in the value of concept C_j and a decrease of the value of concept C_i will cause a decrease in the value of concept C_j. Conversely, if a negative causality is between two concepts, then $w_{ij}<0$; this means that the increase in the first concept involves the decrease in the value of the second concept and the decrease of concept C_i causes the increase in value of C_j.. In absence of relationship between concepts then, the value of w_{ij} is equal to 0.

Typically, the value of each concept is calculated, computing the influence of other concepts to the specific concept, by applying the calculation rule shown in the Equation (1), proposed by Kosko (1986):

$$x_i(t) = f\left(\sum_{\substack{j=1 \\ j\neq i}}^{n} x_j(t-1)w_{ij}\right) \tag{1}$$

where, $x_i(t)$ is the value of concept C_i at time t, $x_j(t-1)$ is the value of concept C_j at time $(t-1)$, w_{ij} is the weight of the interconnection between concept C_i and concept C_j, n is the dimension of the concepts set, and $f(\cdot)$ is a characteristic threshold function. It is also important to highlight that, in some situation, it is important to take into account the precedent value of a concept. This means that the considered system has memory of the past. For this reason, it is necessary to apply the calculation rule shown in the Equation (2), as proposed by Stylios et al. (1999):

$$x_i(t) = f\left(k_1 \sum_{\substack{j=1 \\ j\neq i}}^{n} x_j(t-1)w_{ij} + k_2 x_i(t-1)\right) \tag{2}$$

where $x_i(t-1)$ represents the the value of concept C_i at time $(t-1)$, the parameter k_2 represents the weight of the contribution of the previous value of the concept C_i in the computation of the new value, and the k_1 expresses the influence from the interconnected concepts in the configuration of the new value of the concept, x_i. Specifically, the values k_1 and k_2 satisfy the Equation (3):

$$0 < k_1, k_2 < 1 \tag{3}$$

and generally, the values of two parameters are dependent on each specific FCM. In so doing, the new state vector holds the new values of the concepts after the interaction among concepts of the map. The interaction was caused by the change in the value of one or more conceps.

Moreover, regarding the choice of threshold function, it is important to be clear about the objectives of the analysis. In fact, every usable threshold function has advantages and disadvantages as demonstrated by Bueno et al. (2009). Summarising, in order to obtain the value of a concept, the value of each of its inputs (each antecedent concept is an input) - ranging from *[0 1]* or *[-1 1]* - is multiplied by the respective weight*[-1 1]*; then the results are added and passed by a non-linear function used, among others, to limit the range of possible output values.

Commonly, the dynamics of a FCM consist in its evolution in time, and they are modelled iteratively. Time has to be considered discrete, and the current value of each concept is computed basing on the previous iteration values. Thus, the update of each concept value for the present iteration must occur only after all concepts have been calculated. Evolving through time, the FCM might come to equilibrium, converging to a limit state or after a certain number of iterations depending on threshold function. But, it is important to notice that "time" must be considered an essential parameter during the modelling of a FCM.

FCM also have concepts such as the indirect effect and total stations, allowing precise analysis of the map, just as cognitive maps. The indirect effect is defined now by the operation:

$$I_k(C_i, C_j) = min\{r(C_p, C_{p+1})\} \tag{4}$$

The calculation is based on reports of lower intensity. The symbol $(\mathrm{C_p}, \mathrm{C_{p+1}})$ indicates the path (or paths) between concepts $\mathrm{C_p}$ and $\mathrm{C_{p+1}}$. The equation (4) can be explained with "weak ring in the chain" metaphor. In fact, it is necessary to identify a concepts concatenation as a chain where the weight $r(C_i, C_j)$ represents the hardiness of each chain ring. If in the chain a weak ring exists, it is not possible to consider the chain as a "resistent chain", but the total hardiness of the chain is quantified with the hardiness of the weak ring.

When there is more than a concatenation among the cause node and the effect node, it is useful to define the concept of total effect $T(x,y)$. According to Alexlrod (1976), causal variable C_i's total effect on effect variable C_j is the aggregate sum of all the paths' indirect effects from each causal variable associated with each effect variable, as shown in Equation (5).

$$\mathrm{TE}(\mathrm{C_i}, \mathrm{C_j}) = \max\{\mathrm{I_k}(\mathrm{C_i}, \mathrm{C_j})\} \tag{5}$$

In particular, a positive total effect implies that each indirect effect is also positive; a negative total effect implies that each indirect effect is also negative; an indeterminate effect, on the other hand, implies that some indirect effects manifest positive effects while others manifest negative effects (Kosco, 1986).

Considering the "weak ring in the chain" metaphor, if it is possible to choose what kind of chain it is suitable to use, the chain with highest hardiness value will be used. Therefore, according to the value of hardiness derived by Equation (4), the Equation (5) allows to define what chain is more resistant. In so doing, the chain hardiness identifies the relevance of the first concept in the concatenations on the top event.

Commonly, the dynamics of a FCM consist in its evolution in time, and they are modelled iteratively. Time has to be considered discrete, and the current value of each concept is computed basing on the previous iteration values. Thus, the update of each concept value for the present iteration must occur only after all concepts have been calculated. Evolving through time, the FCM might come to equilibrium, converging to a limit state or after a certain number of iterations depending on threshold function. But, it is important to notice that "time" must be considered an essential parameter during the modelling of a FCM. But, it is important highlight that, considering what has been already said, it is not possible to consider this kind of FCM as "Fuzzy Systems". In fact, the Kosko's approach uses matrix, and it can be inferred using iterative standard algebraic operations. A system, consisting of variables defined with a continuous value, ranging in *[0 1]* or *[-1 1]*, instead of Boolean values should, cannot be called "Fuzzy". Moreover, it cannot be categorised as qualitative systems, because the only qualitative reasoning involved is a direct mapping from a qualitative term to a number, i.e. "*Low=0.25*". In so doing, one of the most important features of the Fuzzy Logic is not considered: the uncertainty is not addressed in any way. For these reasons, Carvalho et al. (1999b) asserted in their work that a FCM is indeed a man-trained Neural Network (Multilayer perceptron), therefore it is not Fuzzy in a traditional sense, and cannot allow exploring usual Fuzzy capabilities. In fact, this approach to the FCM doesn't share the properties of other fuzzy systems and cannot be mixed with traditional fuzzy rules and operations. In so doing, FCM are limited to the representation of simple monotonic causal relations between concepts. FCM are indeed Fuzzy Causal Maps. Right there, in order to avoid this problem, Carvalho et al. (1999a) proposed a Rule Based Fuzzy Cognitive Maps approach (RBFCM). Their method takes advantage of fuzzy sets, inference and logic in its traditional rule based form, as introduced by Zadeh (1965). It consists of fuzzy nodes, for representing concepts, and fuzzy rule bases, for relating and linking concepts. In so doing, concept contains different membership functions which represent the concept's possible values or the possible values of its change.

However, it is important to highlight that, in order to use a real fuzzy approach, some restrictions and conditions exist for the membership functions, according to Carvalho et al. (1999c).

Using the RBFCM approach, it is possible to focus the attention on one of the greatest improvements of it. In fact, RBFCM is the ability to deal with non monotonic and/or asymmetric causal relations. This consideration is very important because, in many real world systems, causal relations cannot be described by a single number or sentence.

2.2 The research approach

The research approach, proposed in this work, consists of three main phases (as shown in

Figure 1):

1) Development of a ***Cognitive Modelling Group***. This phase can be divided into three steps:
   - ***Problem identification***. A clearly specified list of problem is the most suitable basis for identifying potential solutions.
   - ***Definition of the panel of expert***. Each component must be chosen according to criteria of competence and area.

- ***Concepts identification***. The suppliers' selection concepts are identified by literature and the panel of expert experience.

2) Development of ***FCM model.*** This phase is organized into four steps:
   - ***FCM design***. The correlation between concepts is analysed to design FCM.
   - ***FCM refinement***. Interviews with staff, not included in the group of experts, permit to modify FCM adding details that in the previous phases have been omitted or overlooked. After that, the panel of experts will review the validity of work, correcting any errors and, so they make possible to use the FCM for analytical purposes.
   - ***Simulation with designed FCM***. The realised FCM is used in order to obtain system information. An input vector is used in FCM, and the obtained result is opportunely processed to be analysed by experts.
   - ***FCM analysis of results.*** The panel of expert analyses the simulation.
3) ***Suppliers Selection***. The realised FES is tested in order to define a rigorous approach to the supplier selection.

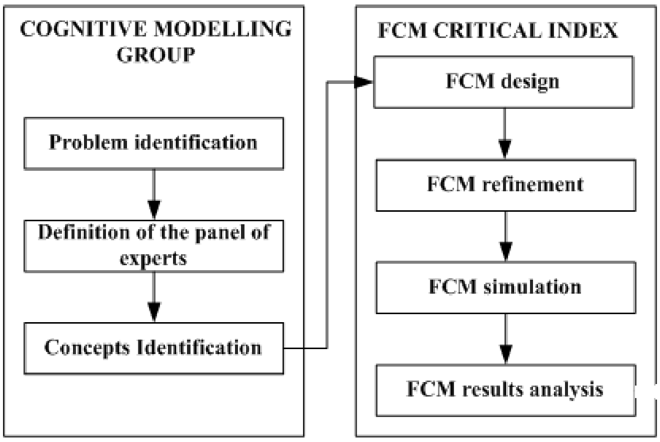

Figure 1: The research approach.

2.2.1 Cognitive Modelling Group

During the "Problem identification" step, the aims and scope of the analysis are defined and classified: environmental aspects connected with the operational activities carried out, safety risk, investment, work orders management, etc. For this reason the requirements, regulations and adequacy criteria of the plant concerning safety and environmental protection must be made clear since they are considered "boundary conditions" in the analysis.

The "Definition of a panel of expert" aims at providing the perspective of individuals with regard to the perception of suppliers' selection in new product development process (NPD). The approach proposed requires developing a "Group Cognitive Mapping". The number of experts is found within the recommended range (Clayton, 1997; Okoli &Pawlowski, 2004).The work carried out by the group consists of two main phases: collection and structuring of knowledge, and conflict. The collection and structuring of knowledge took place in a session of Group Cognitive Mapping, and it can be divided into two phases: the collection and the organization of the inputs of the same individual in a group cognitive map (this phase was called "Concepts Identification"). Regarding this step, the panel of expert described the main aspects of the problems, which influenced their perception of the problem. In particular, the approach proposed in this work tried to take into account the main concepts which influence the the problem. Later, participants created clusters, grouping similar concepts, referring to the same concepts.

The final step in the Group Cognitive Mapping focused on defining the character of causal links between different clusters. Through the identification of the bonds, this approach allows to distinguish main concepts and secondary ones, which plays a key role in the analysis. The next step of the methodological approach consists in the analysis of potential conflicts between the various concepts by assessing the differences between the various mental models. To this end, it was intended to estimate the relative importance of semantic distance the actors attributed to a different aspect of the issue. Dissimilar is the opinion expressed by the actors about the importance of a specific concept; more likely is the emergence of conflicts regarding the information related to that factor.

3 The cases of study

In this Section, the suppliers' selection problem and the problem regarding to the definition of a criticality indicator for the equipment in an Italian refinery have been briefly described, in order to have a description of Charvalo's and Kosko's approaches.

3.1 FCM application in the suppliers' selection sector

3.1.1 The research approach

The research approach, proposed in this work, for developing a supplier selection model, consists in three phases:

1) Development of a ***Cognitive Modelling Group***. This phase can be divided into three steps:
   - ***Problem identification***. A clearly specified list of problem is the most suitable basis for identifying potential solutions.
   - ***Definition of the panel of expert***. Each component must be chosen according to criteria of competence and area.
   - ***Concepts identification***. The suppliers' selection concepts are identified by literature and the panel of expert experience.
2) Development of ***FCM Critical Index.*** This phase is organized into four steps:
   - ***FCM design***. The correlation between concepts is analysed to design FCM.
   - ***FCM refinement***. Interviews with staff, not included in the group of experts, permit to modify FCM adding details that in the previous phases have been omitted or overlooked. After that, the panel of experts will review the validity of work, correcting any errors and, so they make possible to use the FCM for analytical purposes.
   - ***Simulation with designed FCM***. The realised FCM is used in order to obtain system information. An input vector is used in FCM, and the obtained result is opportunely processed to be analysed by experts.
   - ***FCM analysis of results.*** The panel of expert analyses the simulation results in order to define four suitability regions for the suppliers ranking: "High Suitability", "Medium High Suitability", "Medium Low Suitability" and "Low Suitability".
3) ***Suppliers Selection***. The realised FES is tested in order to define a rigorous approach to the supplier selection.

3.1.2 The suppliers' selection results

In order to define the main concepts referring to the suppliers selection, a questionnaire, performed analysing the specific literature, was proposed to the panel of expert. In particular, the questionnaire was realised using the Likert item. Specifically, five ordered response levels were used, although many psychometricians advocate using seven or nine levels; a recent empirical study (Dawes, 2008) found that a 5- or 7- point scale may produce slightly higher mean scores relative to the highest possible attainable score. The format of the used five-level Likert item is: "Strongly disagree"; "Disagree";" Neither agree nor disagree"; "Agree" and "Strongly agree". Table 1 shows all of the defined concepts for the FCM realisation.

Table 1: List of concepts referring to suppliers selection FES.

ID	CONCEPT NAME	TYPE	ID	CONCEPT NAME	TYPE
C1	Experience Planning PM sector	Input	C16	Historycal supplier evaluation	Intermediate
C2	Workload Planning PM sector	Input	C17	Requirements could change	Intermediate
C3	Plannig PM sector equipment	Input	C18	Supplier support could be inadequate	Intermediate
C4	Experience Controlling PM sector	Input	C19	Supplier Quality	Intermediate
C5	Workload Controlling PM sector	Input	C20	Suppliers could deliver product after due date	Intermediate
C6	Controlling PM sector equipment	Input	C21	Extraordinary corrective actions	Intermediate
C7	Project resources amount	Input	C22	Project duration stretches	Intermediate
C8	Supplier dimension	Input	C23	Risk to pay penalties	Intermediate
C9	Historycal delays	Input	C24	It is necessary to reorder items	Intermediate
C10	Historycal defects	Input	C25	Reorder costs	Intermediate
C11	Historycal flexibility	Input	C26	Errors in "delivered product amount"	Intermediate
C12	Project features could be unclear	Input	C27	Errors in "delivered product type"	Intermediate
C13	Desiderate quality level	Input	C28	Quality of supplied product	Output
C14	Quality of Planning PM sector	Intermediate	C29	Procurement costs	Output
C15	Quality of Controlling PM sector	Intermediate	C30	Supplier suitability for the project	Output

At this point, it was necessary to create the Fuzzy Weights Matrix of FCM. This matrix was obtained proposing the concept map to the panel of experts. They rated the various connections using the following evaluations: very low, low, medium, high and extremely high. Table **2** exclusively shows the non-zero values of the matrix.

Table 2: The Fuzzy Weights Matrix of FCM.

Row	Weight	Column	Row	Weight	Column
C1	(-) "sufficient"	C14	C18	(-) "great"	C19
C2	"considerable"	C14	C19	(-) "small"	C20
C3	"small"	C14	C19	(-) "considerable"	C26
C4	(-) "great"	C15	C19	"great"	C27
C5	"considerable"	C15	C19	"small"	C28
C6	"considerable"	C15	C20	"sufficient"	C21
C7	(-) "sufficient"	C18	C20	(-) "small"	C22
C8	(-) "sufficient"	C18	C21	"sufficient"	C22
C9	(-) "small"	C16	C21	"sufficient"	C29
C10	"sufficient"	C16	C22	"great"	C23
C11	"considerable"	C16	C23	"considerable"	C29
C12	(-) "sufficient"	C17	C24	"considerable"	C25
C13	(-) "considerable"	C30	C25	"sufficient"	C29
C14	(-) "considerable"	C17	C26	"great"	C24
C14	(-) "great"	C26	C27	(-) "sufficient"	C24
C14	(-) "sufficient"	C27	C28	"considerable"	C24
C15	(-) "sufficient"	C21	C28	(-) "considerable"	C30
C16	"considerable"	C18	C29	"great"	C30
C17	"sufficient"	C18			

Table 3 shows the concepts relevance on the final concept: "Supplier Suitability for the project". Moreover, it also shows the concept relevance regarding to the FCM structure.

Table 3: Total Effect Matrix.

Concept Name	TE
Experience Planning PM sector	"sufficient"
Workload Planning PM sector	"sufficient"
Plannig PM sector equipment	"sufficient"
Experience Controlling PM sector	(-) "sufficient"
Workload Controlling PM sector	(-) "sufficient"
Controlling PM sector equipment	(-) "sufficient"
Project resources amount	"sufficient"
Supplier dimension	"sufficient"
Historycal delays	(-) "small"
Historycal defects	"sufficient"
Historycal flexibility	"sufficient"
Project features could be unclear	"sufficient"
Desiderate quality level	(-) "considera-
Quality of Planning PM sector	"sufficient"
Quality of Controlling PM sector	(-) "sufficient"
Historycal supplier evaluation	"sufficient"
Requirements could change	"sufficient"

Supplier support could be inadequate	"sufficient"
Suppliers could deliver product after	"sufficient"
Supplied product quality	"sufficient"
Extraordinary corrective actions	"considerable"
Project duration stretches	" considerable"
Risk to pay penalties	"considerable"
It is necessary to reorder items	"sufficient"
Reorder costs	"sufficient"
Errors in "delivered product amount"	"sufficient"
Errors in "delivered product type"	"sufficient"
Quality of supplied product	"considerable"
Procurement costs	(-) "great"

In order to validate the FES functioning, a training input dataset was created and used for simulating the system performance. The obtained "Supplier Suitability" concept values were studied by the expert panel for defining a theory to adopt in real situations. In particular, according to the silhouette statistic (Kaufman and Rousseeuw, 1990), the expert panel decided to cluster data in 4 regions.

As mentioned, the panel of experts formulated the following rule:

- If Supplier Suitability Indicator belongs to cluster "Low", the relative supplier is not suitable for the project;
- If Supplier Suitability Indicator belongs to cluster "Medium Low", the relative supplier could be suitable for the project but this is not recommended, because a high probability to negative results exists;
- If Supplier Suitability Indicator belongs to cluster "Medium High", the relative supplier could be suitable for the project and this is recommended, because a high probability to positive results exists;
- If Supplier Suitability Indicator belongs to cluster "High" the relative supplier is highly suitable for the project, the value for cost ratio is very high.

3.2 Definition of a criticality indicator

3.2.1 The research approach

The research approach, proposed in this subsection, for developing a risk based maintenance model, consists in three phases:

1) Development of a Cognitive Modelling Group. This phase can be divided into three steps:
    - -Problem identification.
    - -Definition of the experts' panel. Each component must be chosen according to criteria of competence and area.
    - -Factors identification. The criticality causes are identified by technical literature, devices datasheets and the historical information regarding each device.
2) Development of FCM Critical Index. This phase can be organized into four steps:
    - -FCM design. The correlation between factors is analysed to design FCM.

-FCM refinement. Interviews with staff, not included in the group of experts, permit to modify FCM adding details that in the previous phases have been omitted or overlooked. After that, the panel of experts will review the validity of work, correcting any errors and, so they make possible to use the FCM for analytical purposes.

-Simulation with designed FCM. The realised FCM is used with in order to obtain system information. An input vector is used in FCM, and the obtained result is opportunely processed to be analysed by experts.

-FCM analysis of results.

3) Development of a Risk Based Inspection & Maintenance (RBI&M) plan that consists in:

-Definition of Inspection and Maintenance Activities

-Scheduling of Inspection and Maintenance activities

3.2.2 The criticality indicator results

Particularly, in this work, for developing an Inspection and Maintenance plan for refinery pumps, an ad hoc panel of experts was created in order to encourage communication and meetings during which the members could contribute their knowledge and information about the processes. The panel was made up of 8 participants, and included 2 academics, whose research studies are mainly focused on Risk Assessment, 2 managers of the company, 2 factory supervisors and 2 operators. This number of participants, which at first sight may seem rather large, derives from the Cognitive Mapping technique. The panel of experts worked for a period of about two weeks in order to outline the main concepts which influence maintenance and for developing FCMs on these concepts.

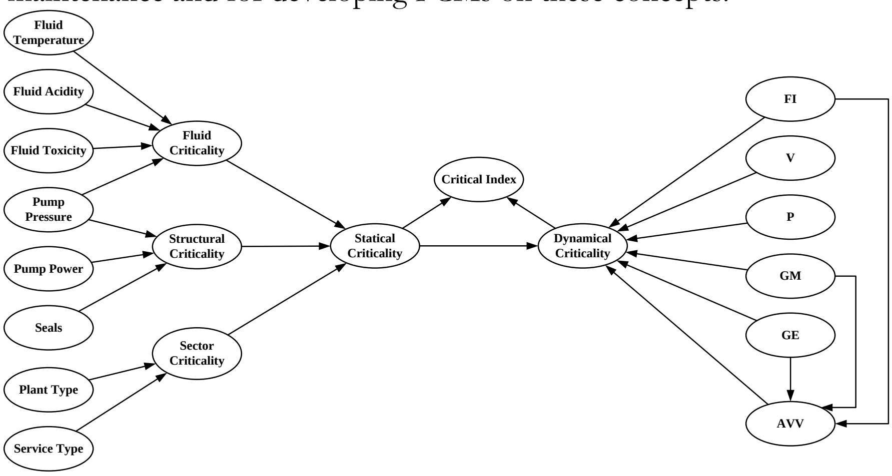

Figure 2: Complete Cognitive Map

Figure 2 shows the complete Cognitive Map. After collecting the failure data and information on the working conditions over a period of 18 months, a significant sample of 176 centrifugal pumps, operating at API refinery, has been obtained. Data collected have been divided into "static data" that regard working conditions of pumps and "dynamic data" that regard the use of the pumps.

In order to analyze the factors affecting the criticality of refinery equipments, it is necessary to conduct the numerical analysis of FCMs. As explained, in this section, the Kosko's approach has been used. Using the total effect value, a ranking of main significant concepts have been defined for understanding the relevance of each concept on critical index (see Table 4).

Table 4: Principal Paths

Path N.	Critical Paths				Indirect effect
1	Fluid Temperature	Fluid Criticality	Static Criticality	Critical Index	0.6
2	Fluid Acidity	Fluid Criticality	Static Criticality	Critical Index	0.6
3	Fluid Toxicity	Fluid Criticality	Static Criticality	Critical Index	0.6
4	Fluid Criticality	Static Criticality	Critical Index		0.6
5	Fluid Losses	Dynamic Criticality	Critical Index		0.6
6	Mechanical failure	Dynamic Criticality	Critical Index		0.6
7	Electrical failure	Dynamic Criticality	Critical Index		0.6
8	Seal	Structural Criticality	Static Criticality	Critical Index	0.5
9	Irregular Functioning	Dynamic Criticality	Critical Index		0.5
10	Irregular Functioning	Start up failure	Dynamic Criticality	Critical Index	0.5
11	Mechanical failure	Start up failure	Dynamic Criticality	Critical Index	0.5
12	Electrical failure	Start up failure	Dynamic Criticality	Critical Index	0.5
13	Start up failure	Dynamic Criticality	Critical Index		0.5
14	Pump Pressure	Fluid Criticality	Static Criticality	Critical Index	0.4
15	Pump Pressure	Structural Criticality	Static Criticality	Critical Index	0.4
16	Pump Power	Structural Criticality	Static Criticality	Critical Index	0.4

In particular, sixteen criticality quadrants of the Cartesian plane can be identified as shown in the Table 5.

Table 5: Classification of the Cartesian plane for the Criticality Areas

	Static Criticality

		$[-1 \quad -0.5]$	$[-0.5 \quad 0]$	$[0 \quad 0.5]$	$[0.5 \quad 1]$
Dynamic Criticality	$[-1 \quad -0.5]$	Low Static and Dynamic Criticality	Medium Low Static and Low Dynamic Criticality	Medium High Static and Low Dynamic Criticality	High Static and Low Dynamic Criticality
	$[-0.5 \quad 0]$	Low Static and Medium Low Dynamic Criticality	Medium Low Static and Medium Low Dynamic Criticality	Medium High Static and Medium Low Dynamic Criticality	High Static and Medium Low Dynamic Criticality
	$[0 \quad 0.5]$	Low Static and Medium High Dynamic Criticality	Medium Low Static and Medium High Dynamic Criticality	Medium High Static and Medium High Dynamic Criticality	High Static and Medium High Dynamic Criticality
	$[0.5 \quad 1]$	Low Static and High Dynamic Criticality	Medium Low Static and High Dynamic Criticality	Medium High Static and High Dynamic Criticality	High Static and High Dynamic Criticality

In the API refinery, according to this research, the 30% (53 pumps) of the pumps is placed in the "Low Criticality Area", the 34% (59 pumps) in the "Medium Low Criticality Area", the 26% (45 pumps) in "Medium High Criticality Area" and finally, the 11% (19 pumps) in the "High Criticality Area".

4 Conclusion

The proposed thesis highlighted the potential of cognitive maps in their explanatory and reflective functions and their value in support of decision making within organizations in a phase of any consolidation of the cognitive distances involved. Intelligent agents use mental models and have various “internal” processes (physical, mental, emotional) as they interact with other agents. Many simulations ignore intra-agent life, or model intra-agent characteristics as discrete from the larger inter-agent simulation. It is possible to use the FCM (an iterative network) to model agent life in a unified continuous way. By the formalisms seen in the previous sections it is possible to define cognitive maps graphically representing the mental structures and mental operations that constitute the components of mental models. Encourage group members to produce their own learning and cognitive maps represent their mental models that can have multiple functions in the formation, whether or not assisted by the network. The considered areas of study are characterized by complexity requiring the investigation of new advanced methods for modelling and development of sophisticated systems. In order to improve the communication between the different actors in relation to the factors, it becomes important to recognize that the mental models that characterize them influence the way they perceive the world and, consequently, the risks. In this work, the analysis of cognitive maps of the various actors has allowed highlighting the links between the causes and the effects. The information collected through this analysis have been used both as a basis for the definition of strategies of risk communication, and as a guide for the negotiation process aimed at reducing existing levels of conflict and, at the same time, at improving the mitigation measures to be taken. The analysis of data collected in this phase of the study made it possible to draw some preliminary communication strategies between the various factors involved. On the basis of the results obtained, it becomes, in fact, important to encourage administrators to increase the dissemination of information about previous responsibilities relating to risk management, and the future ones relating to possible measures to be undertaken in a specific area. This information should concentrate on making explicit the different stages and the actors involved in each of them.

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