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A Fuzzy Cognitive Map Based Intelligent System for Reengineering Manufacturing Systems

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Abstract

Reengineering consists of conceiving the radical improvements that must be introduced into the organization of a manufacturing system so that the product managerial attributes satisfy a target market. Fuzzy cognitive maps are fuzzy signed digraphs that cannot justify their outputs because they are full of feedback loops. This paper presents an intelligent system that supports reengineering. The suggested system uses a new type of neural network that has a fuzzy cognitive map structure but justifies its outputs. The intelligent system is applied to identify the target organization for a problematic manufacturing system. In addition, it is used to generate new types of organizations for manufacturing systems that feed new types of markets.

1 Introduction

Any saleable product possess physical characteristics and managerial attributes. On one hand, the physical characteristics result from the activities that the operators carry out on the materials using machines and tools. These activities constitute the manufacturing process (bottom of Figure 1). On the other hand, the managerial attributes result from the organization of the manufacturing system that makes the product (upper part of Figure 1). The production delay, the percentage of defective products, the product variety and the product cost are examples of managerial attributes. As indicated in Figure 1, the physical characteristics and the managerial attributes of the product must satisfy its target market in order that this one must be sold.

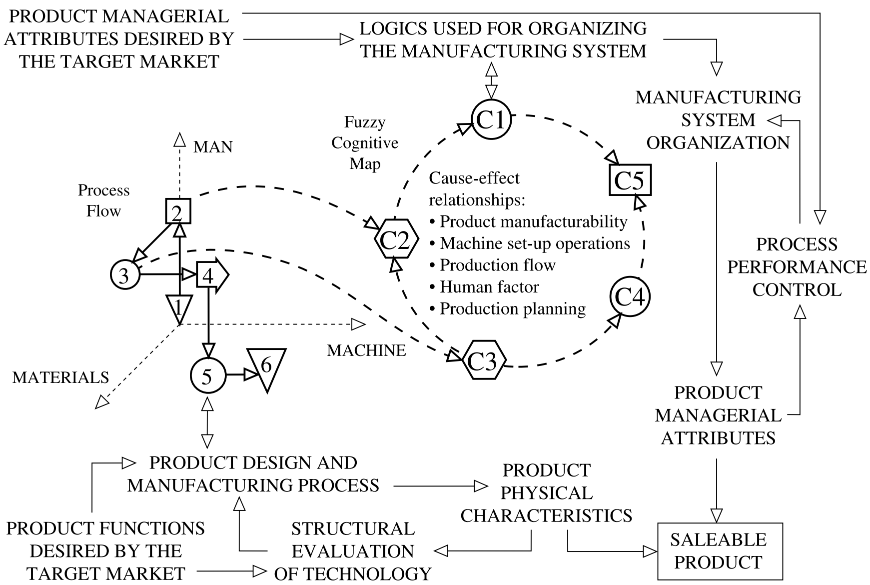

Figure 1: The components of a saleable product: Physical characteristics and managerial attributes. Note that the physical characteristics result from the manufacturing process whereas the managerial attributes result from the manufacturing system organization.

In practice, the product design and the manufacturing process are well defined because they result from careful analyses (Bullinger and Warschat[1]). In spite of this, the serial production makes products whose managerial attributes differ from the ones desired by the target market. In this case, the manufacturing system is named problematic and is therefore necessary to reengineer it. Reengineering consists in conceiving the radical improvements that must be introduced in the organization of the manufacturing system so that the resulting managerial attributes correspond to the ones desired by the target market (Hammer[5]). The new organization is named target organization. At this point, note that “radical improvements” implies modifying the sources that control the current patterns of the managerial attributes. Furthermore, the organization of a manufacturing system is the set of working procedures related to the

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product manufacturability, the machine setup operations, the production flow, the human factor and the production planning (Macedo[8]).

Current tools for reengineering (Manganelli[9]) do not use fuzzy cognitive maps, which are cause-effect signed digraphs full of feedback loops. The latter keep somebody from interpreting the output of the fuzzy cognitive map by going over its cause-effect paths (Kosko[6]). This paper presents an intelligent system named ENREMOS (Expert Neural Reference Model System) that supports reengineering. ENREMOS uses intelligent reference models. Each intelligent reference model is a fuzzy cognitive map which is not full of feedback loops but has a tree structure that allows to output interpretation by going over its cause-effect paths. This interpretation is necessary for the managers acceptance of the improvements suggested by an intelligent model. From this point of view, a reference model is a new type of neural network that differs from the classic ones. The latter include only unexplained cause-effect relationships (Carpenter and Grossberg[3]).

In section 2 of this paper, the structure and use of ENREMOS are presented. In section 3, ENREMOS is applied to identify the target organization for a factory that has to feed two structurally different target markets. In section 4, new types of target markets are assumed and ENREMOS is used to generate new types of factory organizations required to feed these markets.

2 Structure of the Intelligent System

The structure and use of ENREMOS are illustrated in Figure 2. As shown, ENREMOS consists of a knowledge base of intelligent reference models (top right of Figure 2), a network structure matcher (second box in the left side of Figure 2) and an algorithm for optimizing reference models (fourth box in the left side of Figure 2).

The knowledge base of ENREMOS stores intelligent reference models built by crossanalysis of the industry (Macedo and Ruiz Usano[7]). As indicated in the right side of Figure 2, each reference model consists of an objective function and a pseudo fuzzy cognitive map obtained by decomposing the managerial attributes (which are selected state variables) in terms of state and control variables. As indicated in Figure 3, the pseudo fuzzy cognitive map models the behavior of each state variable as the sum of the weighted positive and negative influences that this variable receives from the other variables connected to it. This sum is modulated by a bell shaped function that pushes the final value of the state variable to zero or to one; this function also creates a small feedback loop that includes the same state variable. As for the objective function of the

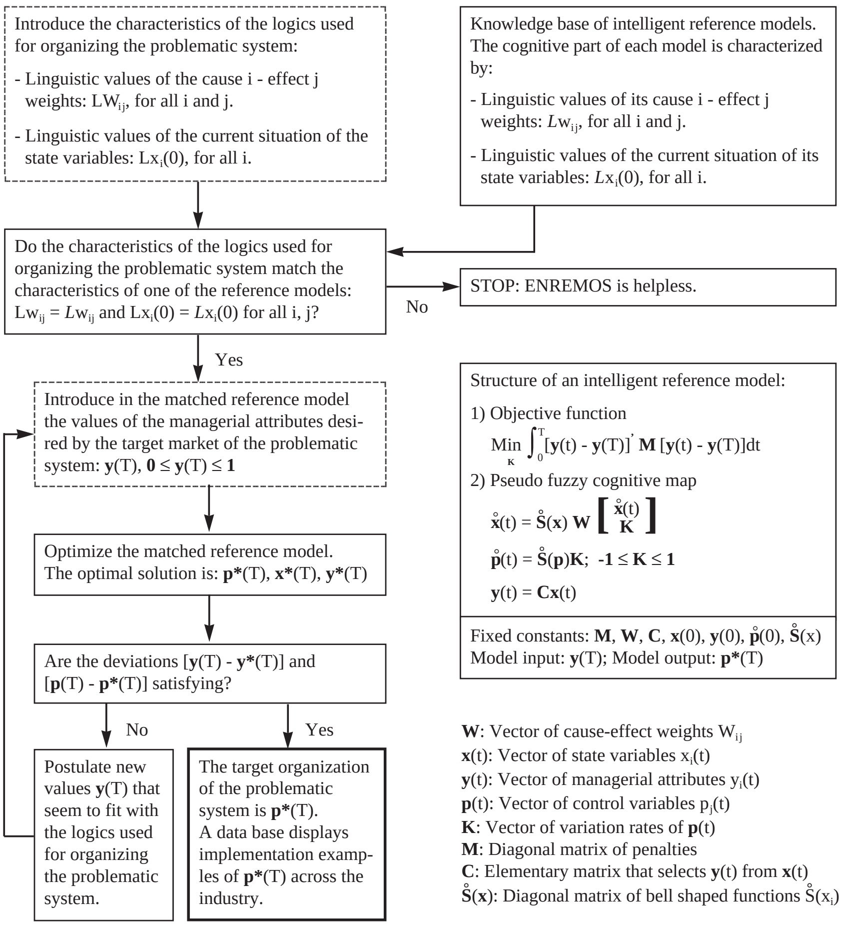

Figure 2: Intelligent system ENREMOS for reengineering the organization of a problematic system. The inputs of ENREMOS are in the dashed boxes while its principal output is in the bold box.

reference model, it is an inversor operator that generates the control variable values which minimize the deviations between the current and the desired values of the managerial attributes.

The network matcher of ENREMOS compares the linguistic values of the cause-effect weights and of the state variables of the analyzed manufacturing system to the ones of the pseudo fuzzy cognitive maps stored in its knowledge base. When a match is identified, the matched reference model is optimized in order to find the target organization for the analyzed factory. When a match is not identified, ENREMOS is helpless. At this point, note that the use of linguistic values is possible due to the well known robustness of the fuzzy cognitive maps (Kosko[6]).

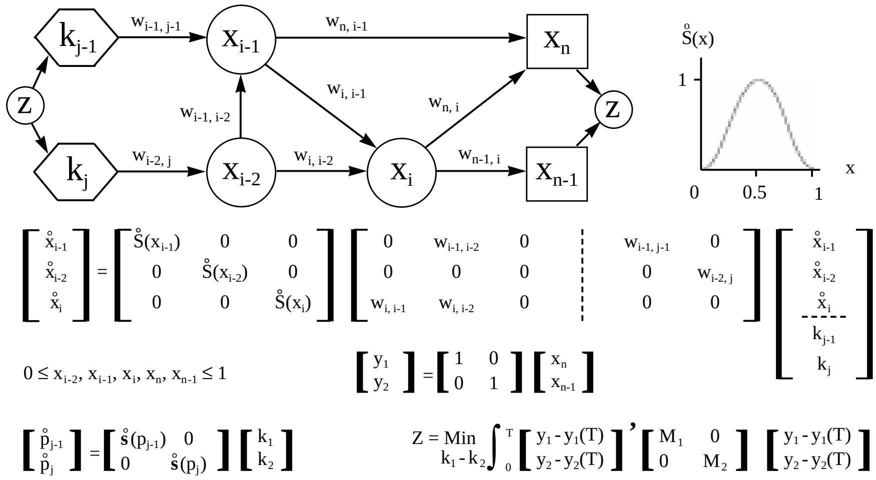

Figure 3: Detailed structure of an intelligent reference model as stored in ENREMOS knowledge base. The state variables are in circles, the control variables in hexagons and the managerial attributes in boxes. Note that the cause-effect weights are fixed values between -1 and +1.

The optimization algorithm included in ENREMOS is a gradient search procedure without derivatives (Adeli[2]) that self-organizes the control variables of the reference model. This selforganization is mainly supported by the feedback loop that includes the objective function of the reference model. This objective function moves the current equilibria of the matched reference model to the equilibria desired by the target market. During this change of equilibria, the bell shaped functions included in the state equations of the reference model push the state variables to zero or to one.

3 Validation of the Intelligent System

In the following paragraphs, ENREMOS is extensively applied to reengineer the organization of a problematic factory. These applications are directed to demonstrate that a reference model can identify the right target organization for a manufacturing system in spite of structural variations in its target market. These applications are also directed to demonstrate that the solution of a reference model can be justified by going over its tree structure. Without loss of generality, the applications are limited to the identification of the improvements in the production planning procedures.

Following the procedure in Figure 2, linguistic values for the causeef fect weights and for the state variables of a problematic factory were introduced in ENREMOS as well as values for the desired managerial attributes; all these values are in Table 1. Then, ENREMOS selected and optimized the reference model in Figure 4 producing the values in Table 1. The optimal values of the control variables in Table 1 constitute the target organization suggested by ENREMOS for the problematic factory.

The analyses in the next two subsections demonstrate that the target organizations suggested by ENREMOS are structurally different, as expected (because the postulated target markets are structurally different). In addition, the suggested organizations correspond to the ones used by factories in reality. These analyses were obtained by interpreting the results of Table 1 and by going over the cause-effect paths of the matched reference model (Figure 4).

3.1 First analysis: World class market

A world class market consists of customers that look for low priced products (COST=0), without defects (DEF=0), quickly delivered (DEL=0), offered in several styles (VAR=1) and delivered on time (LIV=1). For this type of market, ENREMOS suggest the target organization defined by the values of the control variables in Table 1. This target organization is explained in the following paragraphs.

ENREMOS suggests calculating the quantities of the components by decomposing the product (DEC=1) and by equalizing the production cycles of the factory sections to the cycle time of the bottleneck section (ECOU=1). In this way and as indicated by the paths of Figure 4, the section factories become synchronized (SYNC=1) so that the production flow is continuous (FLUXI=1) and the buffer stocks between sections are low (STOT=0). Hence, the machine workload is expected to be low but is in fact high (CHARM=1) due to the use of efficient production sequencing procedures (ORDN=1) and backward planning from the due date (PREB=1). The fact that the machine workload is high decreases the production cost (COST=0). Furthermore, the low buffer stocks reduce the materials' inventory costs (SCOM=0) so that the production cost is further decreased.

In addition, ENREMOS suggests deliveries of small lots of materials (LOTA=0) so that the material requirements and material deliveries are synchronized (SYPF=1). Consequently, the stock of materials per supply cycle is low (STOM=0) and the materials stockout high (PENM=1). In this situation, the production cost is expected to be high but is low

Table 1. Inputs introduced to ENREMOS and resulting outputs.

Inputs and outputs	Target markets of the problematic system			
	Mass	World	Quality	Cheap
Inputs: Desired managerial attributes y(40)				
COST (40)	0	0	1	0
DEF (40)	1	0	0	1
DEL (40)	1	0	1	0
LIV (40)	0	1	0	1
VAR (40)	0	1	0	0
Outputs: controls p*(40)				
AJU (40)	0	0	0	1
COL (40)	0	1	1	0
DEC (40)	0	1	1	0
DRET (40)	1	0	0	0
ECOU (40)	0	1	1	0
FERM (40)	0	1	0	1
FOUR (40)	1	0	0	1
IDEN (40)	0	1	1	0
JAL (40)	1	0	0	1
LOTA (40)	1	0	1	1
LOY (40)	0	1	0	1
ORDN (40)	1	1	0	1
PREB (40)	1	1	0	0
PREV (40)	1	1	0	1
TRAN (40)	1	1	0	1
Outputs: states x*(40)				
CAP (40)	0	1	0	1
CORD (40)	0	1	0	0
CST (40)	1	0	1	0
CHARM (40)	1	1	0	1
DELC (40)	0	1	0	1
ESCM (40)	1	0	1	1
FAC (40)	1	1	0	0
FLUXI (40)	0	1	1	0
PAJU (40)	0	1	1	1
PENM (40)	0	1	1	0
PENP (40)	0	1	0	1
SCOM (40)	1	0	1	1
STOC (40)	1	0	1	0
STOD (40)	1	0	0	1
STOM (40)	1	0	1	1
STOS (40)	1	0	1	0
STOT (40)	1	0	0	1
SYNC (40)	0	1	1	0
SYPF (40)	0	1	0	0
SYPV (40)	1	0	0	0

(COST=0) because the material inventory cost is low (SCOM=0) due to the low stock of materials per supply cycle (STOM=0).

In conclusion, ENREMOS suggests a mix of organizational elements from just-in-time systems and synchronous manufacturing (Chase and Aquilano[4]) as the target organization. This kind of target organization is like the ones currently implemented by firms that supply world class markets.

3.2 Second analysis: Mass market

A mass market consists of customers that accept low priced products (COST=0), offered in few styles (VAR=0), with defects (DEF=1), long delivery delays (DEL=1) and without guarantee of being delivered on time (LIV=0). For this type of market, ENREMOS suggests the target organization defined by the values of the control variables in Table 1. This target organization is explained in the following paragraphs.

As indicated in Table 1, ENREMOS does not require the use of the product decomposition for determining the quantities of components to be produced (DEC=0). In addition, ENREMOS does not require the equalization of the cycles of the different factory sections to the cycle time of the bottleneck section (ECOU=0). Consequently, the section factories are not synchronized (SYNC=0) therefore rendering the production flow discontinuous (FLUXI=0) and the buffer stocks between sections high (STOT=1). Hence, the machines have high workloads (CHARM=1) which are further increased by the use of efficient production sequencing practices (ORDN=1) and backward planning from the due date (PREB=1). The high machine workloads decrease the production cost (COST=0) in spite of the high material inventory cost (SCOM=1) due to the high buffer stocks.

In addition, ENREMOS suggests deliveries of large lots of materials (LOTA=1) so that there is no synchronization between the material requirements and the material deliveries (SYPF=0). Consequently, the stock of materials per supply cycle is high (STOM=1) and the materials stockout is low (PENM=0). The production cost thus diminishes (COST=0) in spite of the high materials inventory cost (SCOM=1). In addition, the large supplied lots increase the discounts per quantity bought (ESCM=1) so that the production cost is further decreased.

In conclusion, ENREMOS suggests target organizations like the ones traditionally found in firms that supply mass markets (Chase and Aquilano[4]).

Objective function: $\mathbf{Z} = \mathrm{Min}\int_0^{40}[DEL(t) - DEL(40)]^2 + [DEF(t) - DEF(40)]^2 + [COST(t) - COST(40)]^2 + 2[VAR(t) - VAR(40)]^2 + [LIV(t) - LIV(40)]^2\,dt$

Pseudo fuzzy cognitive map:

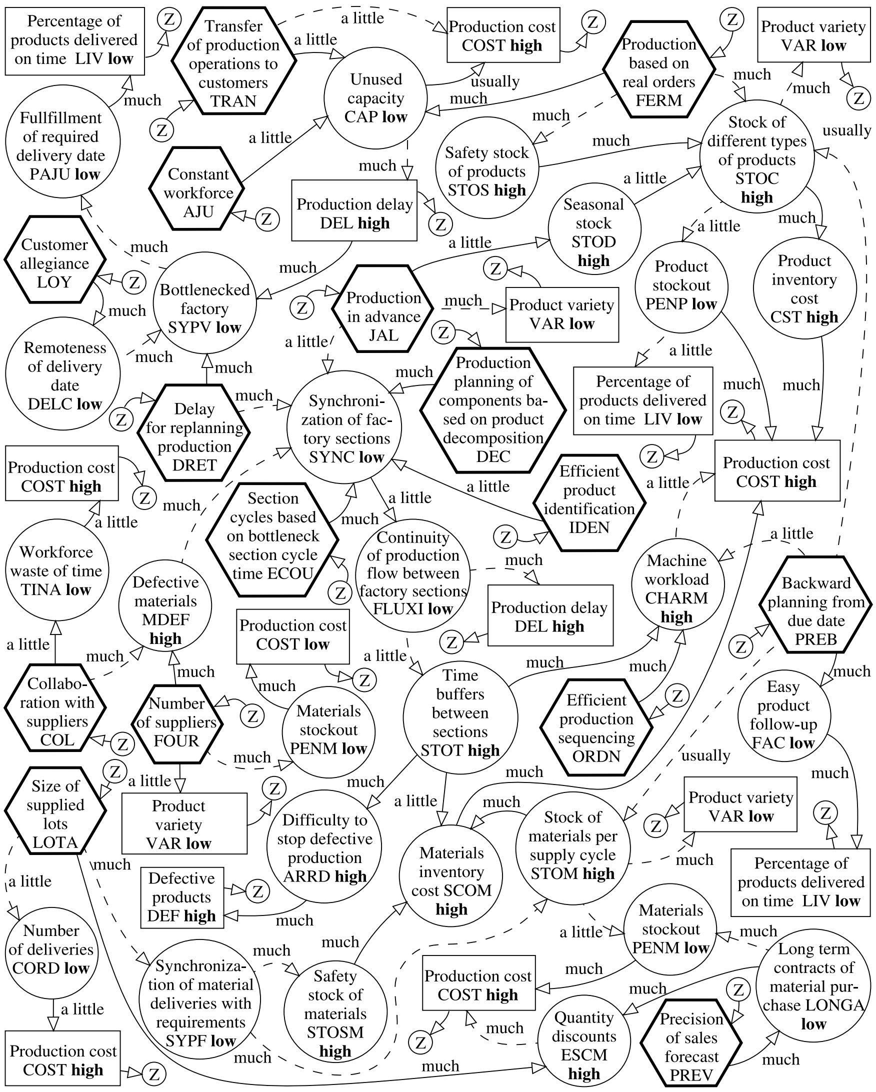

Figure 4: Intelligent reference model of the production planning procedures. The positive cause-effect relationships are in continuous lines and the negative ones in dashed lines. The linguistic values of the cause-effect weights are: A little (0.1; 0.2), usually (0.3; 0.5), much (0.6; 0.8), a lot (0.8; 0.9). The initial values of the state variables which are in bold are: Low (0.1; 0.3), medium (0.4; 0.5), high (0.6; 0.8), very high (0.9; 1).

4 Generation of New Types of Organizations

A reference model is trained with data from the industry so that it can identify organizational improvements as an expert can do. This was demonstrated in section 3 above. However, a reference model can be also used as a simulator in order to identify the manufacturing system organization required to feed any kind of target market. In this case, the reference model generates new types of organizations for the manufacturing systems. In the following paragraphs the results of generating the organization for the problematic factory of section 3 corresponding to two artificial target markets named “cheap market” and “quality market” are reported.

As indicated in Table 1, a “cheap market” requires low priced products (COST=0), offered in few types (VAR=0) but delivered quickly (DEL=0) and on time (LIV=1) even if the products show defects (DEF=1).

For a “cheap market”, the reference model optimization suggests transfering the production operations to the customers (TRAN=1) and maintaining the workforce constant (AJU=1) so that there is some unused factory capacity (CAP=1) that allows for reduction of the production delay. This reduction is enhanced by short replanning delays (DRET=0) and customer allegiance (LOY=1) that allow for the elimination of the bottlenecks in the factory (SYPV=0). In addition, the factory must produce in advance (JAL=1) so that seasonal stocks are accumulated (STOD=1), although the variety of the stocked products remains low (STOC=0) in order to respect the required low variety. At this point, note that the unused factory capacity (CAP=1) should increase the production cost but this one remains low because the materials are bought in large quantities (LOTA=1) so that they benefit from quantity discounts (ESCM=1). Furthermore, the number of suppliers is high (FOUR=1) so that the materials stockout is low (PENM=0). At this point, note that the production in advance avoids the synchronisation of the production sections (SYNC=0) so that buffer stocks between the machines are created (STOT=1). These buffer stocks increase the machine workloads (CHARM=1) so that the production cost is still lowered, as required.

As indicated in Table 1, a “quality market” requires high priced products (COST=1), without defects (DEF=0), with long delivery delays (DEL=1), offered in few types (VAR=0) and without guarantee of being delivered on time (LIV=0).

For a “quality market”, the reference model solution suggests to plan the components production by decomposing the product (DEC=1), to calculate the section cycles using the bottleneck section cycle time (ECOU=1), to reduce the replanning delay (DRET=0), to make efficient product classification (IDEN=1) and to collaborate with the suppliers in order to reduce the defective materials (MDEF=0). These measures allow for the synchronization of the factory sections (SYNC=1) so that the production flow becomes continuous (FLUXI=1) and the time buffers between sections low (STOT=0). In this context, the difficulty in stopping the defective production dimishes (ARRD=0) in such a way that the number of defective products decreases as required.

In conclusion, the target organizations that the reference model solutions suggest in order to feed the "cheap market" and the "quality market" are coherent with the managerial attributes desired by these markets. At this point, note that other organizations can be easily generated by the reference model after introducing the desired managerial attributes in ENREMOS.

5 Conclusions

On one hand, intelligent systems for reengineering of manufacturing systems must justify their suggested improvements. On the other hand, fuzzy cognitive maps cannot justify their suggestions. This paper has introduced a new type of neural network named intelligent reference model that justifies its outputs. The experiences have demonstrated that an intelligent reference model suggests the right target organization for a problematic manufacturing system. In addition, an intelligent reference model is able to generate new and coherent organizations for manufacturing systems that feed new types of target markets.

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