An Intelligent System Dynamics Based Controller for Fuzzy Managerial Systems

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The target organization of a manufacturing system is the one that allows to make products whose managerial attributes (production delay, defective product rate, production cost and product variety) satisfy a target market. A fuzzy controller that generates the target organization of a manufacturing system is presented (Figure 1). This new type of controller, named organizational fuzzy controller (OFC), is an alternative tool to fuzzy expert systems. The OFC does not require membership functions, fuzzy logic and defuzzification procedures. In addition, the OFC can generate target organizations (controls) adapted to structural variations in the desired managerial attributes.

The OFC is based on two well known properties of system dynamics models: Robustness of their state variable behaviors to small perturbations in the parameters of the model; and, self-organization of their state variables to strong variations on the control variables. The OFC is constituted by a qualitative simulation model and by the optimization of a function of an energy function that feedbacks this model (Figure 2). The cause-effect relationships of the qualitative model and the form of the energy function are chosen so that known pairs of desired managerial attributes (state variables) and target organizations (control variables) are reproduced.

The OFC works in the following form (Figure 3). First, the desired managerial attributes and the current values of the cause-effect weights and of the state and control variables of the system being analyzed are introduced in the OFC. Then, the OFC identifies and optimizes the reference model whose intervals of robustness match the introduced information. The optimal values of the control variables, which are expressed as binary values, constitute the target organization of the system being analyzed.

A linguistic point of the reference model is the one that is defined by the managerial attributes desired by the target market and by the intervals of robustness of the initial values of the state and control variables. The reference model in Figure 4 is robust for the indicated intervals of the cause-effect weights. In addition, this reference model is valid for two linguistic points. The first point is defined by the desired managerial attributes marked W in the box that includes the energy function and by the intervals of robustness included in the flags marked W, in Figure 4. The second point is defined by the desired managerial attributes marked M in the box that includes the energy function and by the intervals of robustness included in the flags marked M.

The following tests are conducted in order to verify the validity of the OFC. The reference model is solved with one of the point values (in bold in Figure 4) of each one of the two linguistic points mentionned previously. The generated values of the control variables (upper right values in the flags of Figure 4) correspond to the right values.

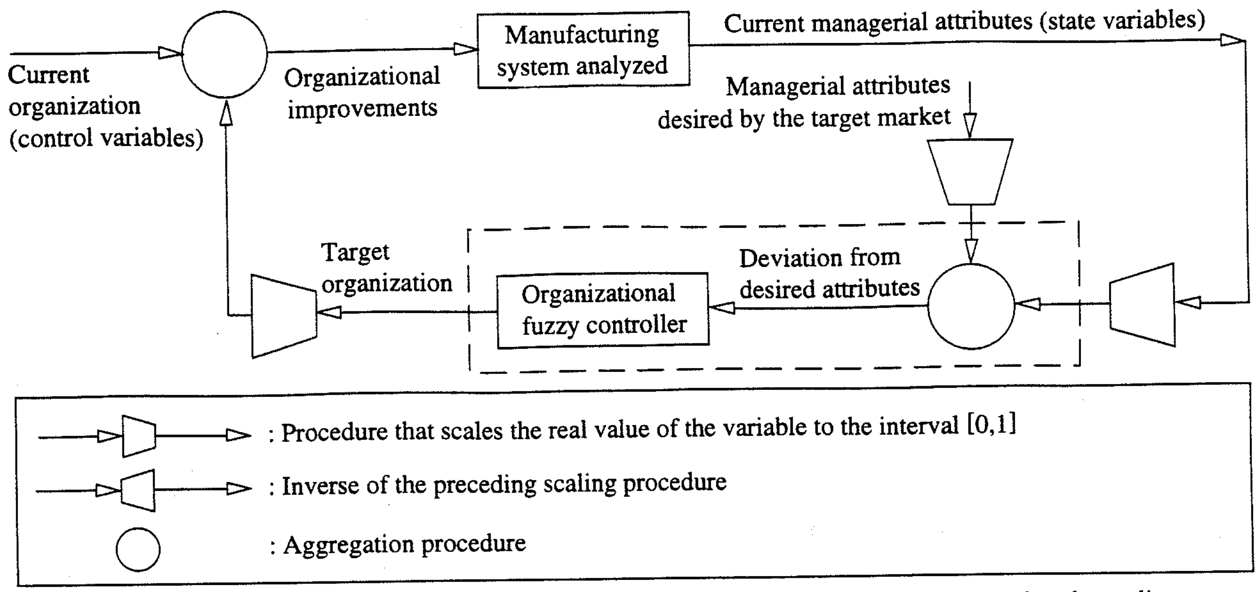
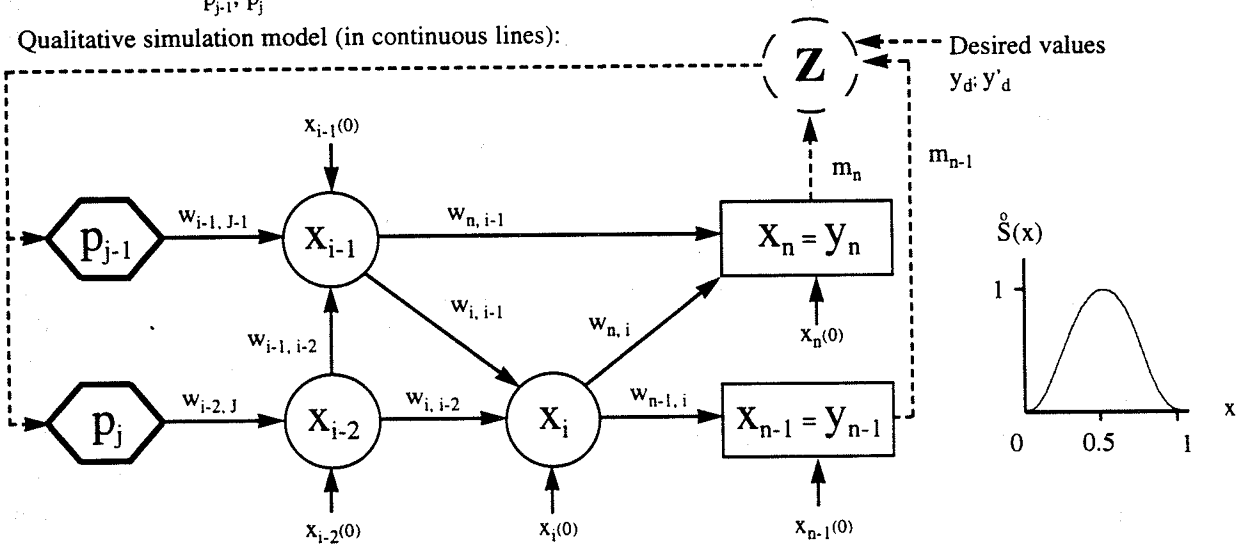


Figure 1. Big picture of the fuzzy controller of the manufacturing system organization. Note that the scaling procedures are not part of the fuzzy controller.

Energy function: $\min_{\mathring{p}_{j-1},\, \mathring{p}_j} Z = \int_0^T m_n [y_n - y_d]^2 + m_{n-1} [y_{n-1} - y'_d]^2 \, dt$

Qualitative simulation model (in continuous lines):

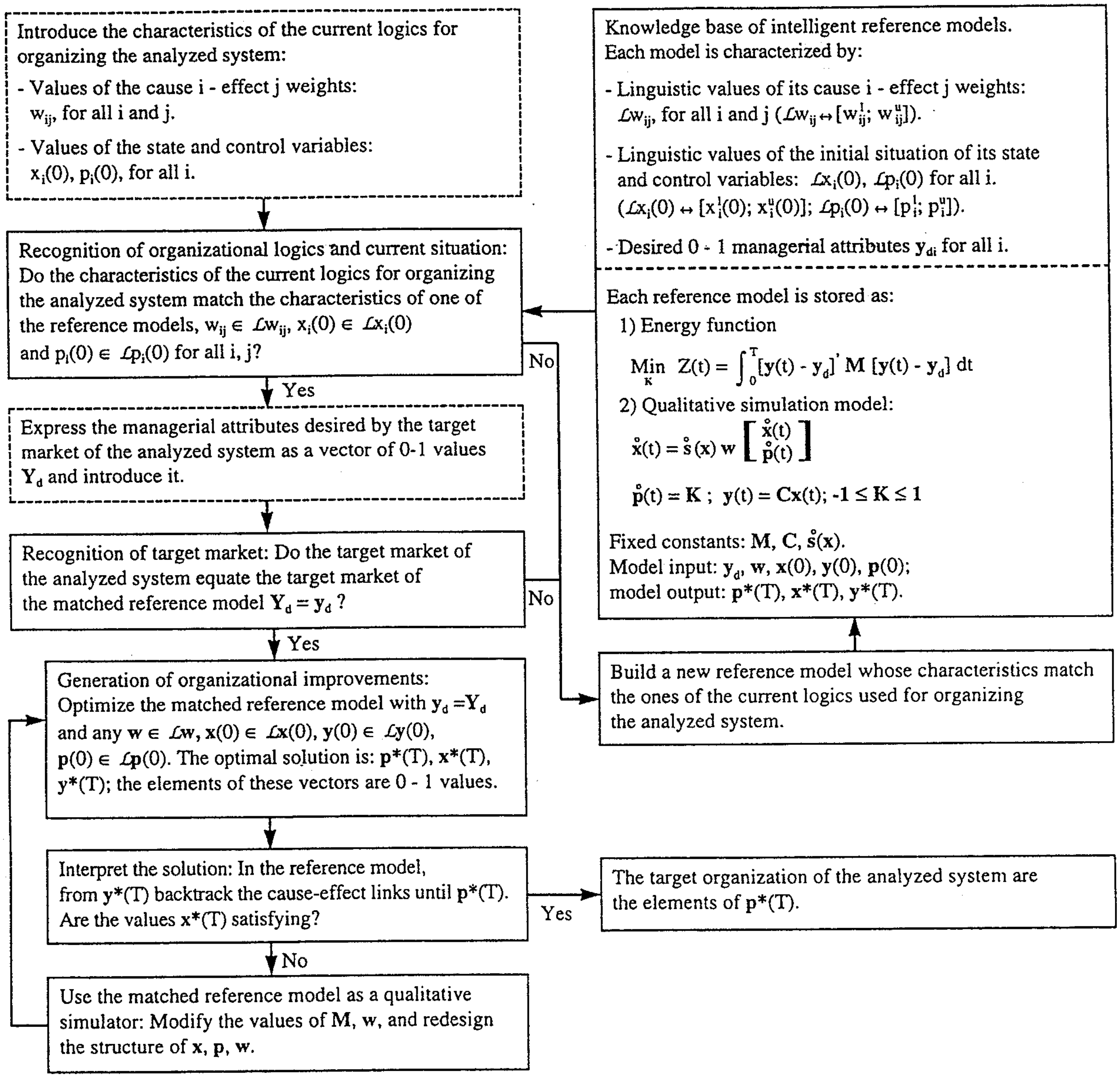


$$\begin{bmatrix} \mathring{x}_{i-1} \\ \mathring{x}_{i-2} \\ \mathring{x}_i \end{bmatrix} = \begin{bmatrix} \mathring{S}(x_{i-1}) & 0 & 0 \\ 0 & \mathring{S}(x_{i-2}) & 0 \\ 0 & 0 & \mathring{S}(x_i) \end{bmatrix} \left[\begin{array}{ccc|cc} 0 & w_{i-1,i-2} & 0 & w_{i-1,J-1} & 0 \\ 0 & 0 & 0 & 0 & w_{i-2,J} \\ w_{i,i-1} & w_{i,i-2} & 0 & 0 & 0 \end{array}\right] \begin{bmatrix} \mathring{x}_{i-1} \\ \mathring{x}_{i-2} \\ \mathring{x}_i \\ \hline \mathring{p}_{J-1} \\ \mathring{p}_J \end{bmatrix}$$

$p_{j-1}(t) = \int_0^T \mathring{p}_{j-1}\, \mathring{s}(p_{j-1})\, dt;\quad p_j(t) = \int_0^T \mathring{p}_j\, \mathring{s}(p_j)\, dt;$

Inputs: y_d, y'_d; Outputs: $p_{j-1}(T)$, $p_j(T)$; Constants: $0 \le x_{i-1}(0), x_{i-2}(0), x_i(0), x_{n-1}(0), x_n(0) \le 1$; $0 \le m_{n-1}, m_n$, all $w \le 1$

Figure 2. Detailed structure of an intelligent reference model which is composed of an energy function and a qualitative simulation model. The state variables are in circles, the control variables in hexagons and the managerial attributes in boxes.



w	Vector of cause-effect weights w_{ij}
w^l	Lower bound of robustness of w
w^u	Upper bound of robustness of w
$x(t)$	Vector of state variables x_i
$x^l(0)$	Lower bound of robustness of $x(0)$
$x^u(0)$	Upper bound of robustness of $x(0)$
$y(t)$	Vector of managerial attributes y_i
$p(t)$	Vector of control variables p_j
$p^l(0)$	Lower bound of robustness of $p(0)$
$p^u(0)$	Upper bound of robustness of $p(0)$
K	Vector of variation rates of $p(t)$
M	Diagonal matrix of penalties M_i
C	Elementary matrix that selects $y(t)$
I	Identity matrix
T	Final time
$\mathring{S}(x)$	Diagonal matrix of bell shaped functions $\mathring{S}(x_i)$
y_d	Vector of desired managerial attributes
$t = 0$	Time of the initial equilibrium
$t = T$	Time of the final equilibrium

Figure 3. Use of the organizational fuzzy controller. The intervals of robustness $w^l \le w \le w^u$; $x^l(0) \le x(0) \le x^u(0)$; $p^l(0) \le p(0) \le p^u(0)$ in the reference model are expressed as linguistic values $\mathcal{L}w$, $\mathcal{L}x(0)$, $\mathcal{L}p(0)$. The variables are scaled so that $0 \le x(0), p(0) \le 1$ and $-1 \le w \le 1$. In addition, the controller always generates $0 \le x(T), p(T) \le 1$.

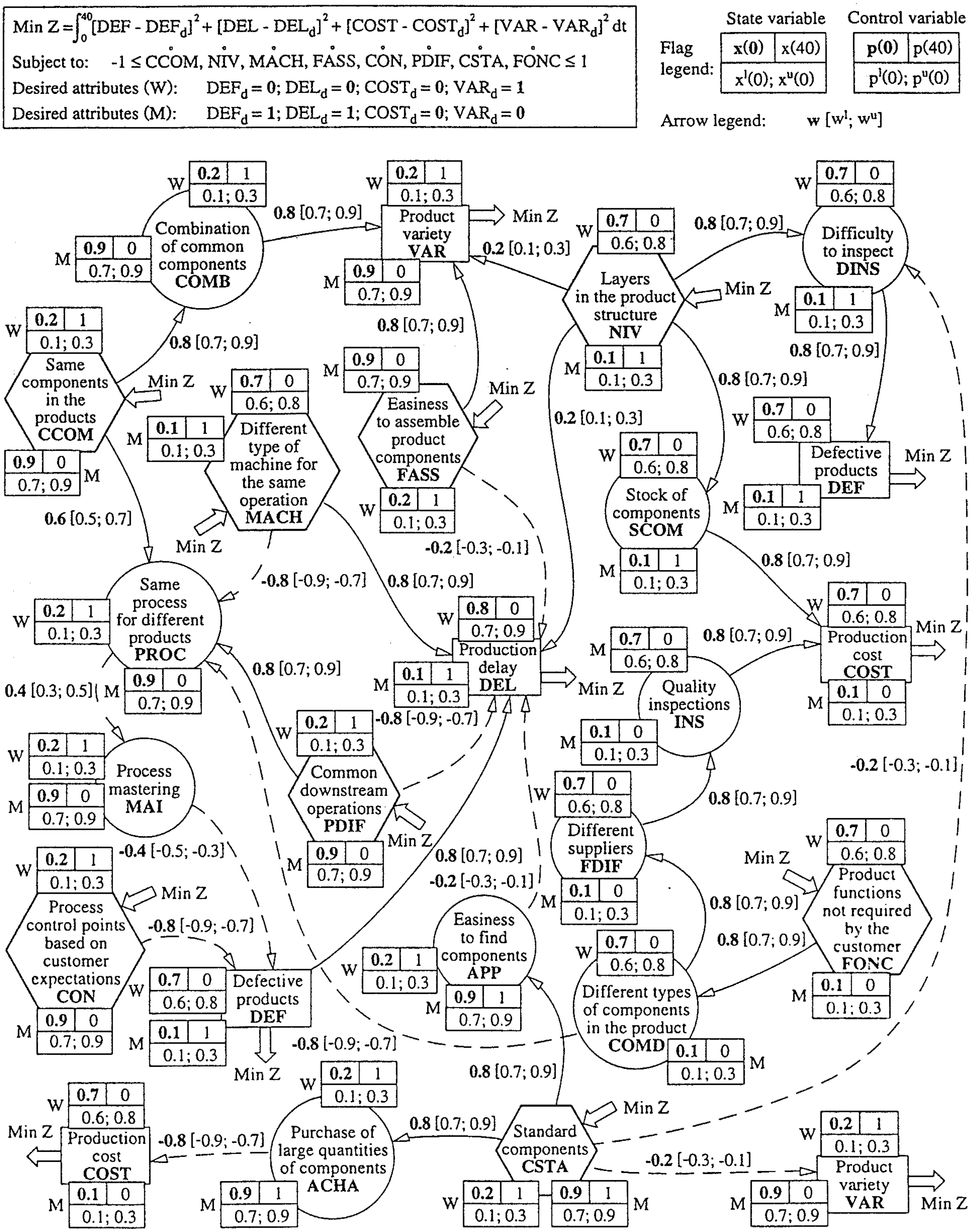


Figure 4. Intelligent reference model of the product structure. The letters W and M identify the equilibria for a world class market and a mass market. The final equilibria of each market are obtained by optimizing the reference model with the corresponding initial equilibria in bold. The positive cause-effect relationships are indicated by the continuous arrows and the negative ones by the dashed arrows.