An Expert System for Conceiving Company Wide Quality Control Strategies

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Abstract

Currently there are three methods for conceiving company wide quality control strategies, the participative approach, the simulation approach and the benchmarking approach. All of these methods present shortcomings. This paper presents a new qualitative method based on system dynamics and an expert system that includes this new method. The expert system is applied to conceive the company wide quality control strategy of a manufacturing firm.

1. INTRODUCTION

A product of quality is the one that satisfies the physical and managerial characteristics expected by the customer (Mizuno, 1989). The physical characteristics of the product are the ones associated to the structure of the product (precision, strength, dimensions) while the managerial characteristics are the ones associated to the management of the system that makes the product (delivery delay, cost, variety of models). A company-wide quality control (CWQC) strategy or total quality control strategy "involve the whole company -every division and every worker at every level- and requires the integration of such formerly independent functions as raw material purchasing, work procedure analysis, work procedure management and inspection" (Mizuno, 1989, p.16). Hence, the conception of a CWQC strategy is a conceptual step before the detailed design and implementation of the improvements. A CWQC strategy includes only the profiles of the improvements because its main goal is to guarantee that these improvements will together produce a product of quality.

What the customer desires exactly is a difficult question and it is not the goal of this paper to answer it. It is assumed that a product is of quality when it shows "zero" defects, "zero" delivery delay, "zero" cost and an "infinity" variety of models. These desired characteristics come from the Just-in-Time systems goals (Gilbert, 1990). However, the firms that best satisfy the customer's desires (the industry leaders) have

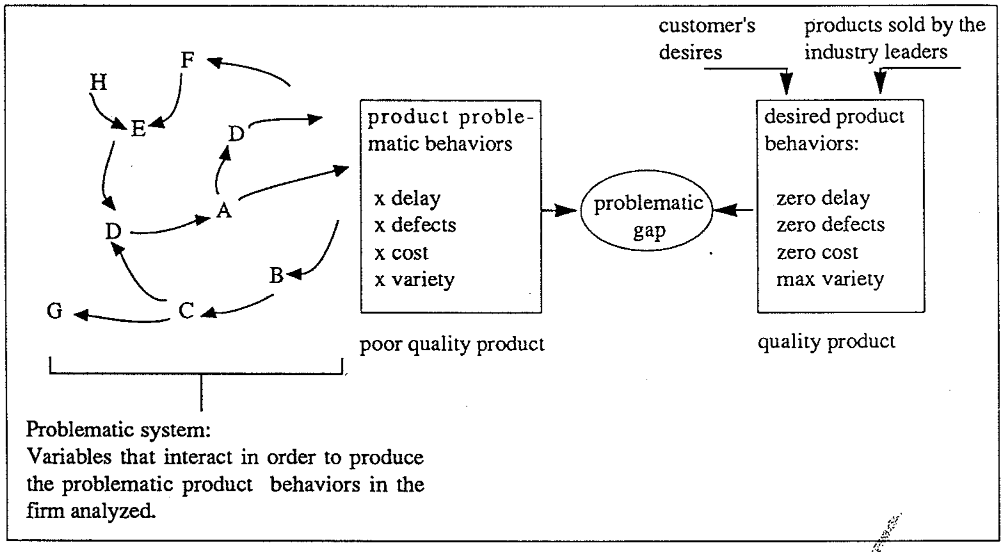

Figure 1. A company wide quality control strategy: Given a set of problematic product behaviors, identify what variables of the problematic system modify and how to modify them in order that the desired product behaviors be reached.

Methods to conceive company wide quality control strategies	Principal characteristics and shortcomings
Participative approach (Ozeki, 1990)	A cause effect diagram that describes the problematic system is built by a participative approach. The CWQC strategy is found by identifying the sources of the problematic product behavior using the cause-effect diagram and brainstorming sessions. This method has no tools to quantify the effect of the CWQC strategy on the problematic system.
Simulation approach (Macedo, 1992)	A model of the problematic system is built using system dynamic principles and a continuous/discrete simulation language. The CWQC strategy is found by intensive simulation of the model. Although this method quantifies the effect of the CWQC strategy (and particularly the counterintuitive effects) on the problematic system the construction of the simulation model is long.
Benchmarking approach (Camp, 1989)	A set of indicators that mesure the gap betwen the performance of the problematic system variables and the industry leader system variables are defined. Next, these indicators are measured and the reasons of the superior performance of the industry leader investigated. The CWQC strategy consists of adopting the succesful solutions implemented by the industry leader. The principal problem with this approach is the measurement of the indicators. In addition, the use of quantitative indicators can produce the refusal of the industry leader to cooperate in explaining its superior performance.

Table 1. Principal characteristics and shortcomings of the methods used to conceive company wide quality control strategies.

total or partially implemented Just-in-time systems (Hayes, Wheelwright and Clark, 1988).

As indicated in figure 1, the conception of a CWQC strategy begins when a product is of poor quality and consists of two steps. First, analyzing the current product and manufacturing system in order to identify the set of variables that interact in order to produce a product of poor quality (problematic system). Second, specifying what variables to modify and in what form so that the product becomes one of quality. Currently there exists three methods to conceive CWQC strategies: The participative approach (Ozeki, 1990), the simulation approach (Macedo, 1992) and the benchmarking approach (Camp, 1989). As indicated in table 1, all these methods present shortcomings.

This paper presents a new method for conceiving CWQC strategies that does not show the shortcomings of the current methods. In addition it presents an expert system whose knowledge base is nourished by the CWQC strategies obtained using the new method. In the third part of the paper the use of the new method for conceiving CWQC strategies and the use of the expert system are illustrated in a manufacturing case.

2. THE EXPERT SYSTEM

The suggested expert system is presented in figure 2 and shows the three classical components of an expert system: Knowledge base, working memory and inference engine (Badiru, 1992). The knowledge base stores the reference structures, i.e. the structures of the problematic systems whose CWQC strategy is known. The working memory stores the structure of the problematic system under analysis. Finally, the inference engine is the set of procedures that verify if the structure in the working memory matches one of the reference structures in the knowledge base. If yes, the CWQC strategy becomes known from the knowledge base. When the matching is not possible, the inference engine calls an external program in order that the user finds the CWQC strategy by simulating the system dynamics model of the problematic system. Once the CWQC strategy is obtained it is added to the knowledge base as well as the structure of the corresponding problematic system.

The structure of a system dynamics model is ordinarily represented by a level-rate model (Richardson, 1981). But, this latter generates a set of nonlinear integral equations complex enough to be stored in the knowledge base of an expert system. In order to eliminate this problem, the level-rate model of the problematic system (first box in figure 2) must be built using integral equations that have the following structure:

$$X_k = X_j - dt \cdot RT_{jk} \cdot [X_j \cdot \log(X_j)] \qquad (1)$$

$$X_0 \text{ known}, \; 0 \leq X_0 \leq 1 \qquad (2)$$

$$RT_{kl} = A \cdot X_k + B \cdot RT_{jk} + C \cdot P_k \qquad (3)$$

$k=kl=t;\; j=jk=t-1;\; 0 \leq t \leq T$

where:

	A : Impact of a level variable on X
X_k : Level variable at time k	B : Impact of a rate variable on X
RT_{kl}: Rate variable at time kl	C : Impact of a control variable on X
P_k : Control variable at time k	dt : Interval of time

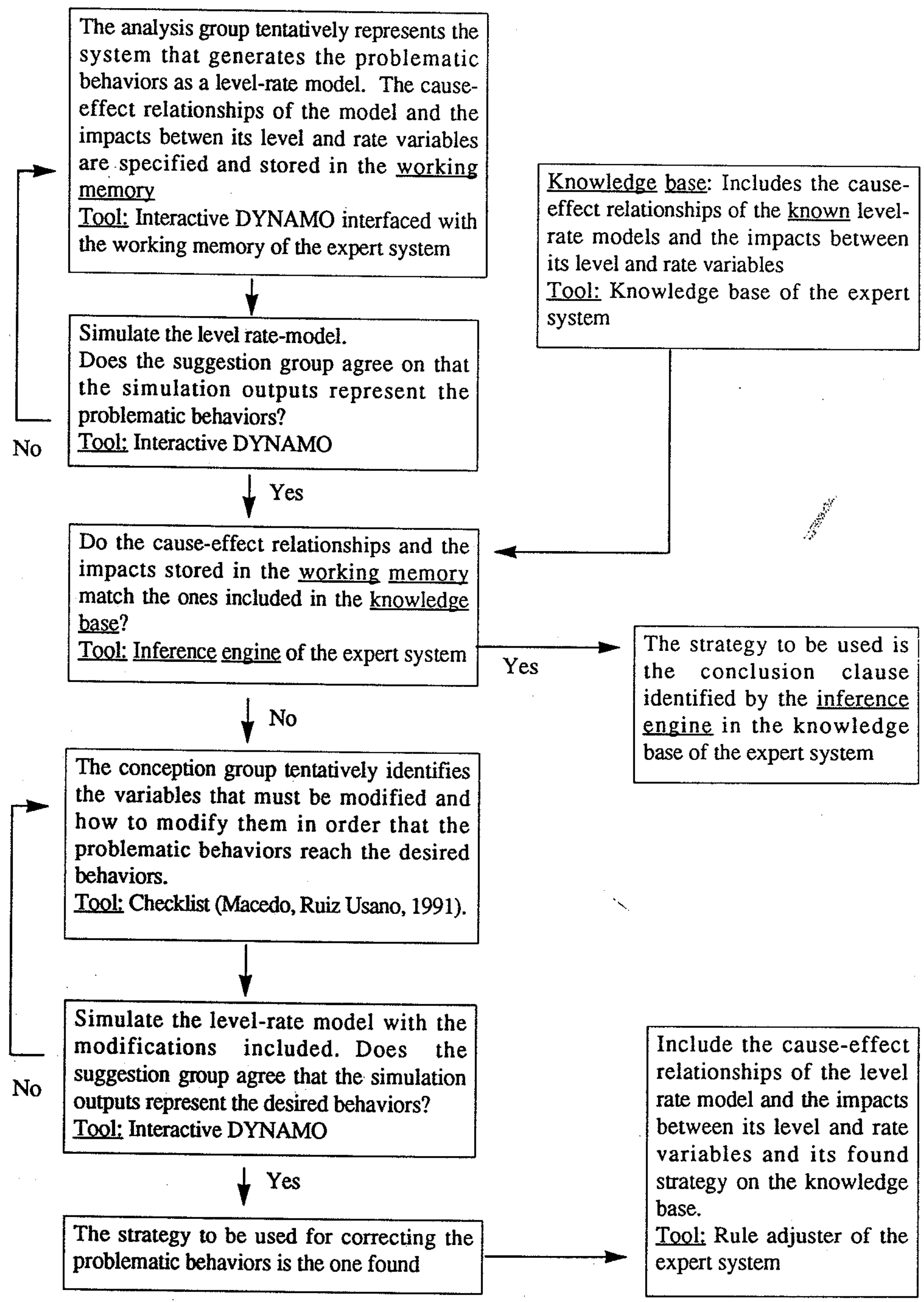

Figure 2. An expert system for conceiving company wide quality control strategies. Note that the expert system uses a participative approach with two groups: the analysis group and the conception group.

As noted any level variable has an initial value between 0 and 1 so that the modulating factor $[X_j*\log(X_j)]$ will produce values for the level variables that are always between 0 and 1. In addition, only two data must be specified in order to build any equation of the level-rate model: if there is a cause-effect relationship between two variables and the value of the impact coefficient A, B or C[1]. These two data for all linked variables define completely the structure of the level-rate model. These two data can be easily stored in the knowledge base of an expert system.

The searched CWQC strategy is constituted by the new values of the control variables P and the coefficients A, B and C that modify the current behaviors of the level variables so that they reach the desired behaviors. Note that the new values of A, B, C and P can strengthen or weaken the current links between the variables or create new links.

The suggested expert system was implemented using VP-EXPERT shell (Badiru, 1992) that uses production rules for representing knowledge and backward and forward chaining as search procedures.

3. A CASE STUDY

The use of the expert system (figure 2) will be illustrated by applying it to conceive the CWQC strategy of a sector of a manufacturing firm. Simultaneously additional characteristics of the expert system will be presented.

Most of the time the product's technical characteristics are well known but the product is of poor quality because the system that makes it is badly organized. Hence, the conception of a CWQC strategy consists finally in specifying the profiles of the changes that must be introduced in the organization of the manufacturing system. These changes belong to six sectors: product structure, manufacturing flow, set up operations, human factor, production planning and automation (Macedo and Ruiz Usano, 1991). In order to shorten this paper the CWQC strategy must be limited to the set up operations in a small factory producing paper napkins[2].

The napkins are made automatically in a machine that stamps, folds and puts in boxes the pieces of paper that it receives. The production director wants to reduce as much as possible the current production delay and the percentage of defective napkins produced by the napkins machine.

[1] Note that the impact coefficients follow the ordinary rules of system dynamics methodology. Hence, when the impact coefficient is positive, the growth (decline) of the cause variable produces the growth (decline) of the effect variable. On the other hand, when the impact coefficient is negative, the growth (decline) of the cause variable produces the decline (growth) of the effect variable.

[2] In practice it is suggested to include the six sectors above in the level-rate model because they are interrelated. This can be done without problems because the form of the equations (1), (2), (3) do not limit the size of the level-rate model. In addition, the tools for implementing the expert systems can accept hundreds of production rules.

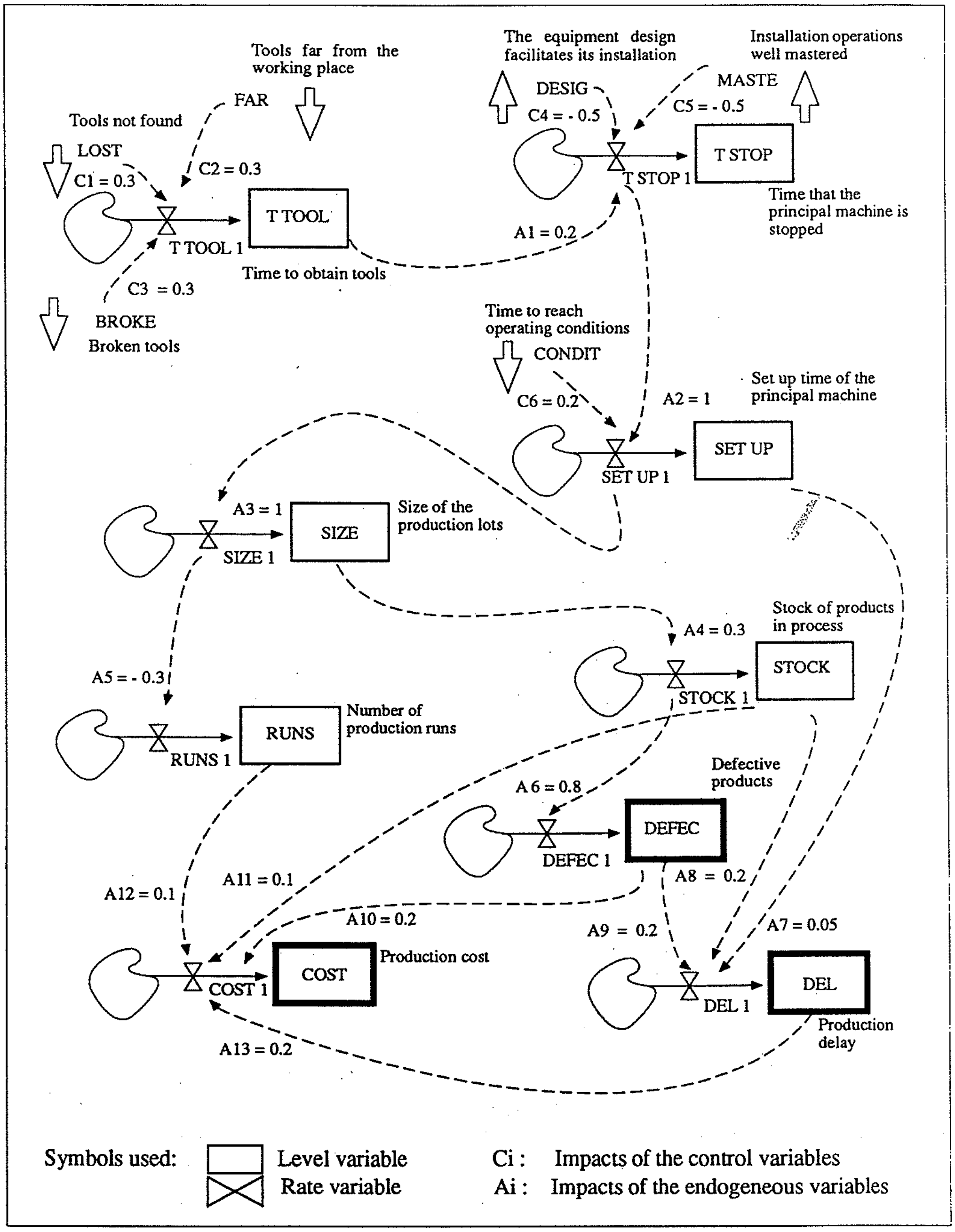

Figure 3. Level-rate model for the set-up operations of the paper napkins machine. Note that the problematic variables are in dark lines while the strategy is constituted by the simultaneous increase ⇧ and decrease ⇩ of the indicated control variables.

As the first box of figure 2 indicates, a level-rate model is constructed. This one is shown in figure 3 and the output of its simulation is in figure 4. Its construction began by writing on a blackboard the problematic variables DEL, DEFEC and COST. Next, the workers and managers related to these variables (analysis group) suggested the causes of their high patterns and the associated impact coefficients. This information was added to the model and the model was simulated. Following the resultant outputs, some variables were eliminated and new ones added until the high patterns of DEL, DEFEC and COST were generated. These high patterns can be explained by looking at figure 4 and following the paths of figure 3: LOST, FAR, BROKE are high enough, DESIG, MASTE low enough and CONDIT high enough that SETUP is high so that STOCK grows producing the growth of DEFEC and DEL.

It is important to note that the abstraction level used for representing the set-up operations in figure 3 is higher than the one used in detailed discrete simulation and in traditional system dynamics. The level-rate model is a meta-model that does not represent the time-space details of the current organization but that captures the resultant behavior patterns using qualitative signs (values and signs of the impact coefficients that emerge from the past experiences of the participants).

The CWQC consists of decreasing LOST, FAR, BROKE, increasing DESIG, MASTE and decreasing CONDIT (figure 3). This means reducing the distance that separates the tools from the working place, reducing the tools unavailable or broken, redesigning the current equipment so that it becomes easy to install, training the operators so that they master the installation operations and decreasing the time that the principal machine needs to reach acceptable operating conditions. As indicated in figure 5, this strategy once introduced in the level-rate model produces the desired behaviors.

The CWQC strategy was found by a conception group constituted by managers and workers of the quality leader factory in the paper napkins sector. As indicated in figure 2, this group used simulations of the level-rate model to confirm the effects of its suggestions (this step is necessary because the humans misperceive the effects of the feedback loops). The high level managers of the leader factory were not opposed to the participation of their workers in the improvement conception group of a competitor. These managers considered that the kind of information required from their workers (values and signs of the impact coefficients) do not represent confidential information. This event demonstrates that the qualitative level-rate models by avoiding the quantitative measurements allow to implement the benchmarking foundations (table 1).

Once the CWQC strategy is known, it is introduced in the knowledge base of the expert system as well as the structure of the associated level-rate model (figure 3). This is done using production rules as in figure 6. The last rule of the knowledge base, the one that includes as a conclusion clause the known CWQC strategy, can have the following form (see figure 3):

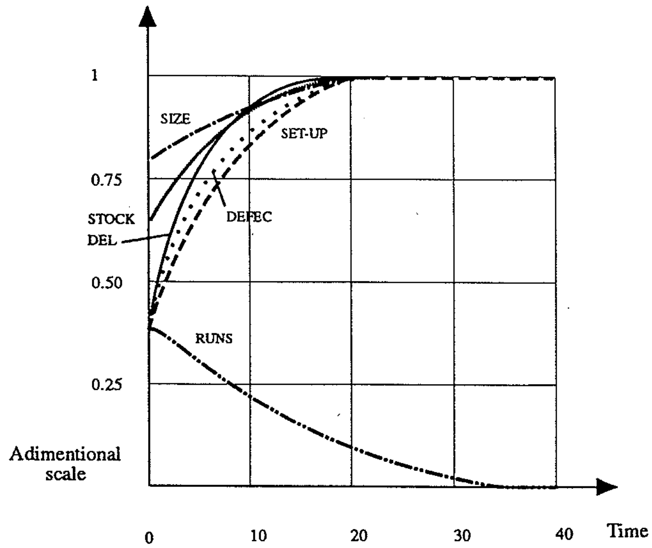

Figure 4. Pattern behaviors obtained by simulating the level-rate model with the current values of the control variables: LOST = 1; FAR = 1; BROKE = 1; DESIG = 0.1; MASTE = 0.1; CONDIT = 0.3. The symbol used are: SIZE (size of the production lots), SET UP (set up time of the principal machine), DEFEC (defective products), STOCK (stock of products in process), DEL (production delay), RUNS (number of production runs).

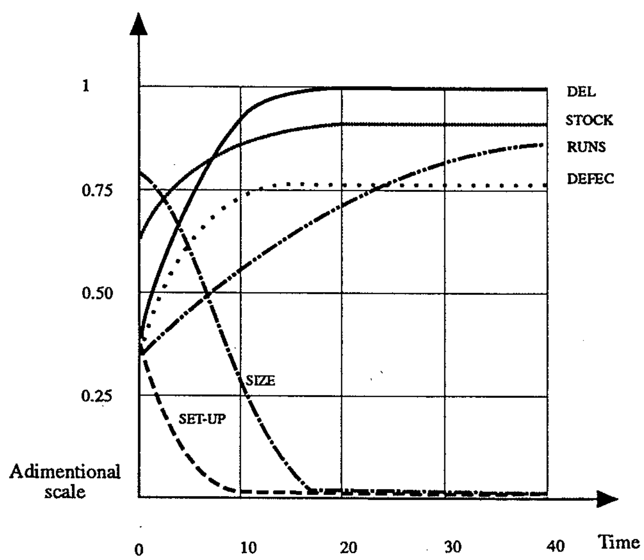

Figure 5. Pattern behaviors obtained by simulating the level-rate model with the CWQC strategy included: LOST = 0.01; FAR = 0.01; BROKE = 0.01; DESIG = 0.3; MASTE = 0.3; CONDIT = 0.01. The symbol used are: SIZE (size of the production lots), SET UP (set up time of the principal machine), DEFEC (defective products), STOCK (stock of products in process), DEL (production delay), RUNS (number of production runs).

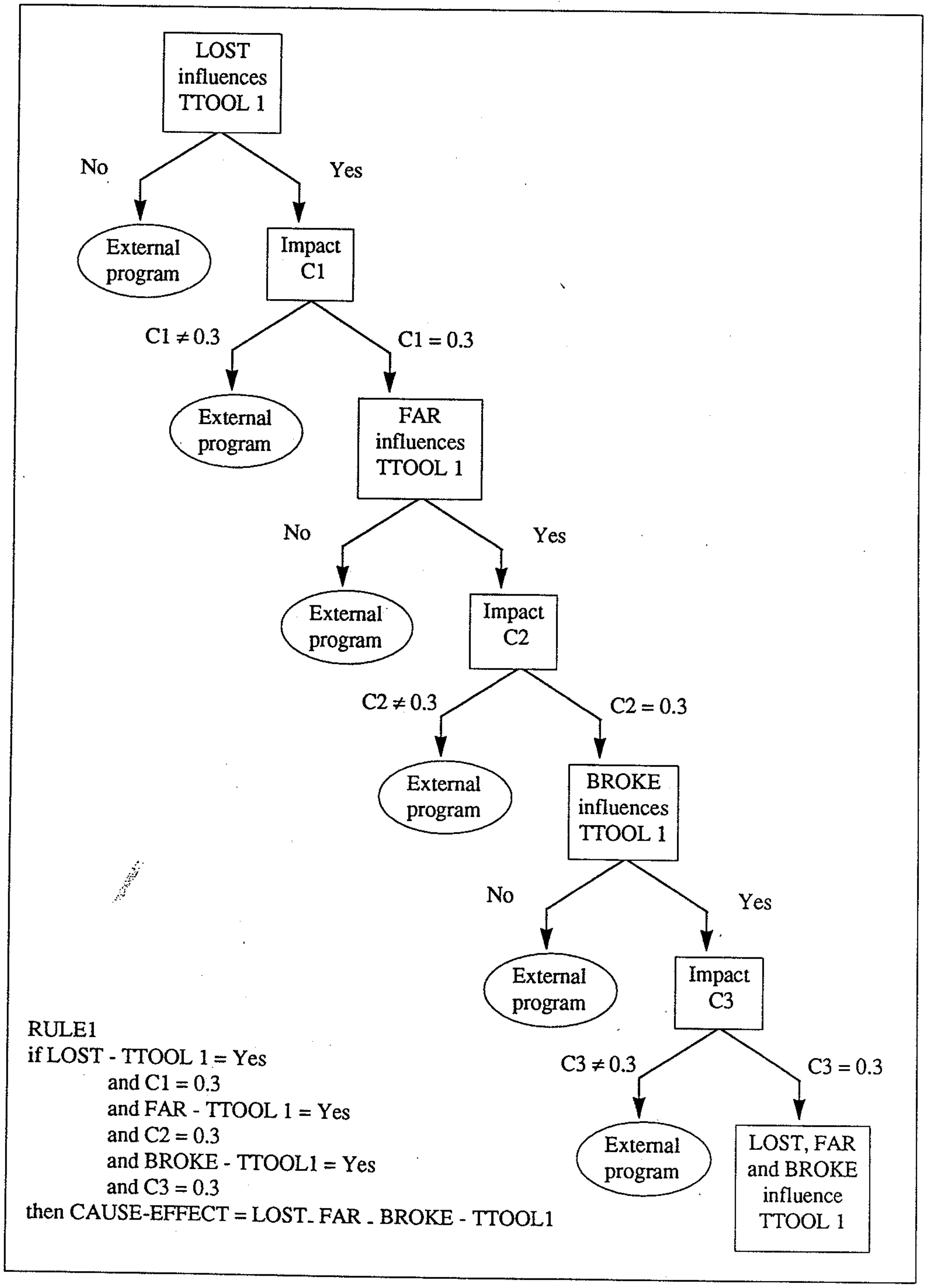

Figure 6. Rule 1 of the knowledge base that represents the structure of the level-rate model. The variables used are defined in figure 3.

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IF CAUSE-EFFECT=RUNS_STOCK_DEFEC_DEL-COST
        AND RUNS_COST1=YES
        AND A12=0.10
        AND STOCK_COST1=YES
        AND A11=0.10
        AND DEFEC_COST1=YES
        AND A10=0.20
        AND DEL_COST1=YES
        AND A13=0.20
THEN STRATEGY=DECREASE_LOST_FAR_BROKE_INCREASE_DESIG_
                    MASTE_DECREASE_CONDIT
```

Hence, when another paper napkin factory wants to reduce the production delay and the percentage of defective products of its paper napkin machine it can profit of the knowledge base just created. It must introduce the structure of its particular level-rate model (cause-effect relationships and values of the impact coefficients) in the working memory of the expert system. If this structure corresponds to the one analyzed in this paper, the expert system will answer with the CWQC strategy to be used. With the progressive use of the expert system, the knowledge base will be enriched so that the use of simulation exercises for conceiving the CWQC strategies will become unnecessary.

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